BULLETIN 64

water resources of the central new york region

William G. Weist, Jr. and G. L. Giese
U. S. Geological Survey

STATE OF NEW YORK
CONSERVATION DEPARTMENT
WATER RESOURCES COMMISSION

WATER RESOURCES OF THE CENTRAL NEW YORK REGION

BY

WILLIAM G. WEIST, JR. and G. L. GIESE
U. S. GEOLOGICAL SURVEY

Prepared by

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
in cooperation with

NEW YORK WATER RESOURCES COMMISSION

STATE OF NEW YORK
CONSERVATION DEPARTMENT
WATER RESOURCES COMMISSION

Bulletin 64
1969

STATE OF NEW YORK CONSERVATION DEPARTMENT - WATER RESOURCES COMMISSION

MEMBERS

R. Stewart Kilborne............................Conservation Commissioner

J. Burch McMorran..........................Commissioner of Transportation

Louis J. Lefkowitz...................................Attorney General

Hollis S. Ingraham, M. D. ....Commissioner of Health

Don J. Wickham.....................Commissioner of Agriculture and Markets

Neal L. Moylan...................................Commissioner of Commerce

John J. Burns.................................Office for Local Government

ADVISORY MEMBERS

David C. Knowlton...................................Representing Industry

Leonard DeLalio (Alternate).......................Representing Agriculture

Michael Petruska...................................Representing Sportsmen

Willard L. Reading (Alternate).........Representing Political Subdivisions

Robert S. Drew...............................Secretary to the Commission

STATE OF NEW YORK CONSERVATION DEPARTMENT - DIVISION OF WATER RESOURCES

F. W. Montanari...................................Assistant Commissioner

N. L. Barbarossa.......................................Assistant Director

E. L. Vopelak..Director of Planning

UNITED STATES
DEPARTMENT OF THE INTERIOR
walter J. Hickel, Secretary
GEOLOGICAL SURVEY

William T. Pecora...Director

Ernest L. Hendricks.....................................Chief Hydrologist

George E. Ferguson...................................Regional Hydrologist

Garald G. Parker.....................................District Hydrologist

CONTENTS

ILLUSTRATIONS

ILLUSTRATIONS (Continued)

TABLES

WATER RESOURCES OF THE CENTRAL NEW YORK REGION

by

William G. Weist, Jr. and G.L. Giese

ABSTRACT

This report summarizes the available data on the water resources of the Central New York Region which includes Cayuga, Cortland, Madison, Onondaga, and Oswego Counties--an area of 3,622 square miles centering around Syracuse. The 740,000 people living in the region use about 310 mgd (million gallons per day) of water for domestic and industrial purposes. About 90 percent of this water presently comes from surface-water sources.

The region includes parts of four major drainage basins: the Mohawk River, the Oswego River, the Susquehanna River, and the Lake Ontario plains. Streamflow in the region is highly variable both from time to time, and from place to place. Generally, flow is greatest during March through May and lowest during July through September. During periods of low flow, most of the water comes from ground-water discharge. Streams such as Chittenango Creek, that have large areas of storage in lakes, swamps, or extensive permeable deposits along them, have larger, more dependable low flows than do streams that lack such storage areas. These latter streams may even go dry during periods of deficient rainfall. The only streams with a minimum average 7-day, 2-year flow greater than 50 cfs (cubic feet per second) are the Salmon River below Salmon River Reservoir and the Seneca, Oneida, and Oswego Rivers. Over half of the streams in the region have a minimum average 7-day, 2-year flow less than 2 cfs. In general, the quality of the surface water tends to be better than that of the ground water except during periods of base flow, when most of the flow comes from the ground water.

Ground water in the region occurs in both consolidated deposits (bedrock) and unconsolidated deposits (sand, gravel, etc.). The bedrock can be divided into seven units on the basis of similarity of lithology and hydrologic properties. These units are, in ascending order from north to south: lower shale, sandstone, sandstone-shale, dolomite, middle shale, limestone, and upper shale. In all of these units, ground water occurs chiefly along bedding planes and joints. In the more soluble units, such as the limestone and middle shale, these openings have been enlarged by solution. The middle shale unit contains considerable amounts of gypsum and salt, which are soluble in water; thus its water is almost invariably of very poor quality. Water from the limestone is likely to be very hard, but usable, whereas water from the remaining bedrock units is generally of better quality.

The best sources of ground water in the region are the unconsolidated deposits of sand and gravel in the major valleys. The amount of water

available from these deposits commonly can be increased through induced recharge or artificial recharge. A total of more than 240 mgd can be developed from the better sand and gravel aquifers. Water from the unconsolidated deposits generally reflects the quality of the water of the underlying bedrock.

INTRODUCTION

One of the important considerations in planning the development of an area is the quantity and quality of the available water. This study was made by the U.S. Geological Survey in cooperation with the New York State Division of Water Resources to provide the New York State Office of Planning Coordination a summary of the data available on the water resources of the Central New York Region. It is part of the continuing program of water-resources investigations being made by the U.S. Geological Survey, under the direction of Garald G. Parker, District Hydrologist, in cooperation with the Division of Water Resources, New York State Conservation Department, under the direction of Francis W. Montanari, Director, Division of Water Resources.

The region consists of Cayuga, Cortland, Madison, Onondaga, and Oswego Counties, which form parts of four drainage basins (pl. 1). Reports covering the water resources of the Oswego River basin have been written for the Wa-Ont-Ya, the Cayuga Lake, and the Eastern Oswego River Basin Regional Water Resources Planning Boards and are being readied for publication. The data contained in this report for the Central New York Region have been extracted from these reports. Work is in progress on reports for the Susquehanna River Basin Regional Water Resources Planning Boards and work in the Mohawk River basin has recently been initiated. The only published reports on the Central Region are those on the ground-water resources of the Cortland quadrangle (Asselstine, 1946), and on streamflow in the Susquehanna River basin (Hunt, 1967).

Multipurpose planning for the development and management of the water resources in the Oswego and Susquehanna River basins is being done by regional water resources planning boards. These boards have been set up to study the water resources of the region - their present uses, and the feasibility of their future development - and to prepare a comprehensive plan for the protection, conservation, development, and utilization of the water resources. The Cayuga Lake Basin Regional Water Resources Planning and Development Board is responsible for the part of the Oswego River basin draining to the west of Owasco Lake and lying within Cayuga and Cortland Counties. The Eastern Oswego Regional Water Resources Planning Board is responsible for the parts of the Oswego River basin that lie within Madison, Onondaga and Oswego Counties, and the remainder of Cayuga and Cortland Counties. The Eastern Susquehanna Regional Water Resources Planning and Development Board is responsible for that part of the Susquehanna River basin that lies in the five-county area. Regional boards have not yet been organized for the Mohawk River and Lake Ontario Plain basins.

WATER-RELATED PROBLEMS OF THE CENTRAL NEW YORK REGION

Problems related to water in the Central New York Region are of three types: too little, too much, and too poor (fig. 1).

Too little -- throughout large areas of the region it is difficult to obtain more than a few gallons a minute from wells. This is enough for

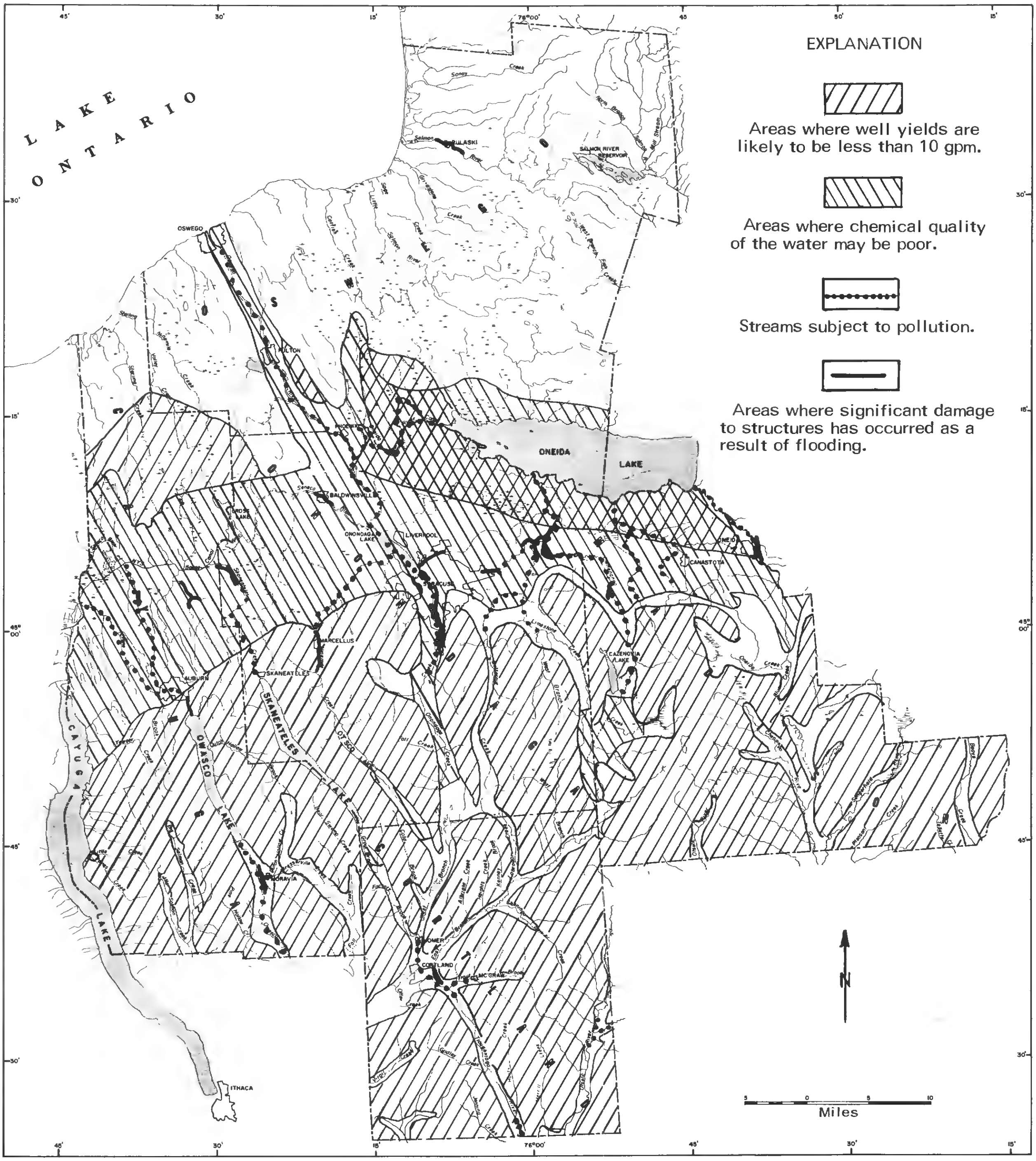

Figure 1.--Generalized water situation.

household use or for watering stock, but is insufficient for most industrial purposes or for developing a public supply. Communities drawing water from surface sources may face serious water shortages during drought periods when streamflow is deficient.

Too much -- flooding can occur along the streams at any time of the year, and there usually is some flooding each year. Floods affecting large areas generally occur only during the spring runoff, whereas the floods resulting from summer storms usually affect only a limited area. Erosion caused by heavy rainstorms and flooding is generally confined to open farmland. Deposition of the sediment derived from this erosion can cause minor problems and inconveniences farther downstream.

Too poor -- most of the water is hard, and may contain higher concentrations of certain minerals than the suggested limits. A broad band across the central part of the region contains ground water that generally is too highly mineralized for uses other than cooling, fire protection, sanitation, or other uses not requiring potable water. Pollution of the surface water is fairly common in and downstream from most of the major communities.

In addition to those problems shown in figure 1, there are other very important water problems which, for lack of complete quantitative information, are not shown. These include irrigation water needs, municipal and industrial water supply needs, needs for fish and wildlife enhancement, flow augmentation, and recreation. Fortunately, most of these problems can be alleviated or controlled. Most of the upland areas, where only low yields can be obtained from wells, are rural areas and large yields are not needed. Large yields can be obtained in most of the major stream valleys, and these generally are the areas where the large communities and heavy industrial development are located. Problems of flooding can be alleviated through proper flow regulation of existing lakes, through the construction of control structures, and through proper flood-plain zoning. Erosion and the resulting sedimentation problem can be controlled through proper land use practices, such as contour plowing, construction of waterways, settling basins, and terracing. Much of the mineralization in the waters can be removed by various, though sometimes expensive methods, and pollution can be reduced by strict control of waste discharge and flow regulation.

AVAILABILITY OF DATA

The availability of water-resource data for the Central New York Region ranges from very complete to very little. Very little information is available at present for the Lake Ontario Plain and that part of the Mohawk River basin contained in the study area (pl. 1). For these areas, most of the information in this report is based upon data for similar areas, general knowledge of hydrology, and from inference. Ground-water data are very complete for the Oswego River basin, and less complete but adequate for the Susquehanna River basin. Surface-water data are comparatively extensive for the Susquehanna River basin and the western part of the Oswego River basin. Surface-water data are less complete for the remaining part of the Oswego River basin. In general, data coverage for the entire Central Region improves from northeast to southwest. Water-quality data coverage is similar to that for ground and surface water throughout the area.

Much more information is needed on industrial use of water in the region. Detailed studies should be made of specific areas before extensive development of their water resources is attempted.

GEOGRAPHY

The Central New York Region has been subdivided into three physiographic regions (pl. 1): the Appalachian Upland, the Erie-Ontario Lowland, and the Tug Hill Upland (Broughton and others, 1966, p. 32, fig. 19).

The Appalachian Upland, which forms the southern part of the region, is characterized by a succession of narrow valleys and steep ridges having a general north-south trend. The land surface rises to the south, reaching altitudes greater than 2,000 feet above sea level in southern Cortland County.

The Erie-Ontario Lowland is formed by the relatively low, flat area south of Lake Ontario. The land surface rises gently away from the lake shore until it meets the abrupt rise of the escarpment that forms the edge of the Appalachian Upland to the south, and the Tug Hill Upland to the east. Low east-west escarpments are formed in places on the lowland by resistant rock units, but in general, there is no dominant trend to the land forms.

The northeast corner of Oswego County is the only part of the region that lies in the Tug Hill Upland. This is a sparsely populated area of broad, flat hills with low relief. The area is poorly drained, resulting in many swamps.

ACKNOWLEDGMENTS

The authors wish to acknowledge the cooperation of their colleagues who collected most of the data on which this report is based: Irwin H. Kantrowitz, Leslie J. Crain, James B. Hood, Charles L. O'Donnell and William J. Shampine (Oswego basin data), and Oliver P. Hunt, Robert D. MacNish, Allan D. Randall, Henry F. H. Ku, and Robert G. LaFleur (Susquehanna basin data). The work and preparation of this report was done under the direction of A. M. La Sala, Chief, Areal Studies Section, U.S. Geological Survey, Albany, N. Y. Detailed reports on the water resources of these basins are now in preparation.

THE HYDROLOGIC CYCLE

The continuous movement of water from the atmosphere to the earth and back to the atmosphere is called the hydrologic cycle. Essentially, the sun acts as a giant pump, providing the energy required for water to move in the hydrologic cycle. Water falls to the earth as precipitation in the form of rain, hail, sleet, or snow. From there it may return to the atmosphere through one of several paths. It may evaporate directly from the surface of the earth where it fell, or it may run off in streams and rivers to lakes or to the ocean, and then be evaporated. Some of the precipitation enters the ground, of which part replenishes soil-moisture deficiencies, part is used by plants, and the rest percolates down to the water table and then moves downgradient toward streams and lakes where it discharges.

In the Central New York Region, most of the precipitation that falls during April through September either runs off or is lost through evapotranspiration. Only during October through March does an appreciable amount of precipitation go into storage.

The average yearly precipitation in the region ranges from less than 32 inches south of Auburn to more than 55 inches in the Tug Hill Upland. The areal variation in annual precipitation is shown in figure 2, adapted largely from a map prepared by Knox and Nordenson (1955). The isohyetal lines for the part of the area in the Susquehanna River basin were taken from a preliminary map prepared by the U.S. Weather Bureau in 1964.

Precipitation is brought to the Central New York Region mainly by two types of storms. The first consists of large-scale, low-pressure systems, the second of small-scale atmospheric disturbances. The actual amount of precipitation that falls in any one place during a storm is controlled to a large extent by topography. When a mass of moist moving air reaches an area of high terrain, the air mass is forced to move upward where it is cooled, and part of the moisture condenses and precipitates. We see, then, from figure 2, that the precipitation contours reflect the topography rather closely.

Lake Ontario exerts a secondary control on precipitation in that moist-air masses coming from the west tend to be channeled over the lake. The main part of these air masses often leaves the lake at its eastern end and begins releasing precipitation as it passes over the higher terrain of the Tug Hill Upland. This explains the high amounts of precipitation received there.

Average annual lake evaporation and water loss for the region, taken from Knox and Nordenson (1955), is shown in figure 3. Water losses consist of evaporation from land and water surfaces and transpiration by plants. The two processes together are often referred to as evapotranspiration. Yearly losses range from about 18 inches in the eastern part of the area to about 22 inches in the central part of the area. Naturally, water losses are greatest during the growing season when plants are active and high air temperatures prevail. Lines of equal lake evaporation are also shown in

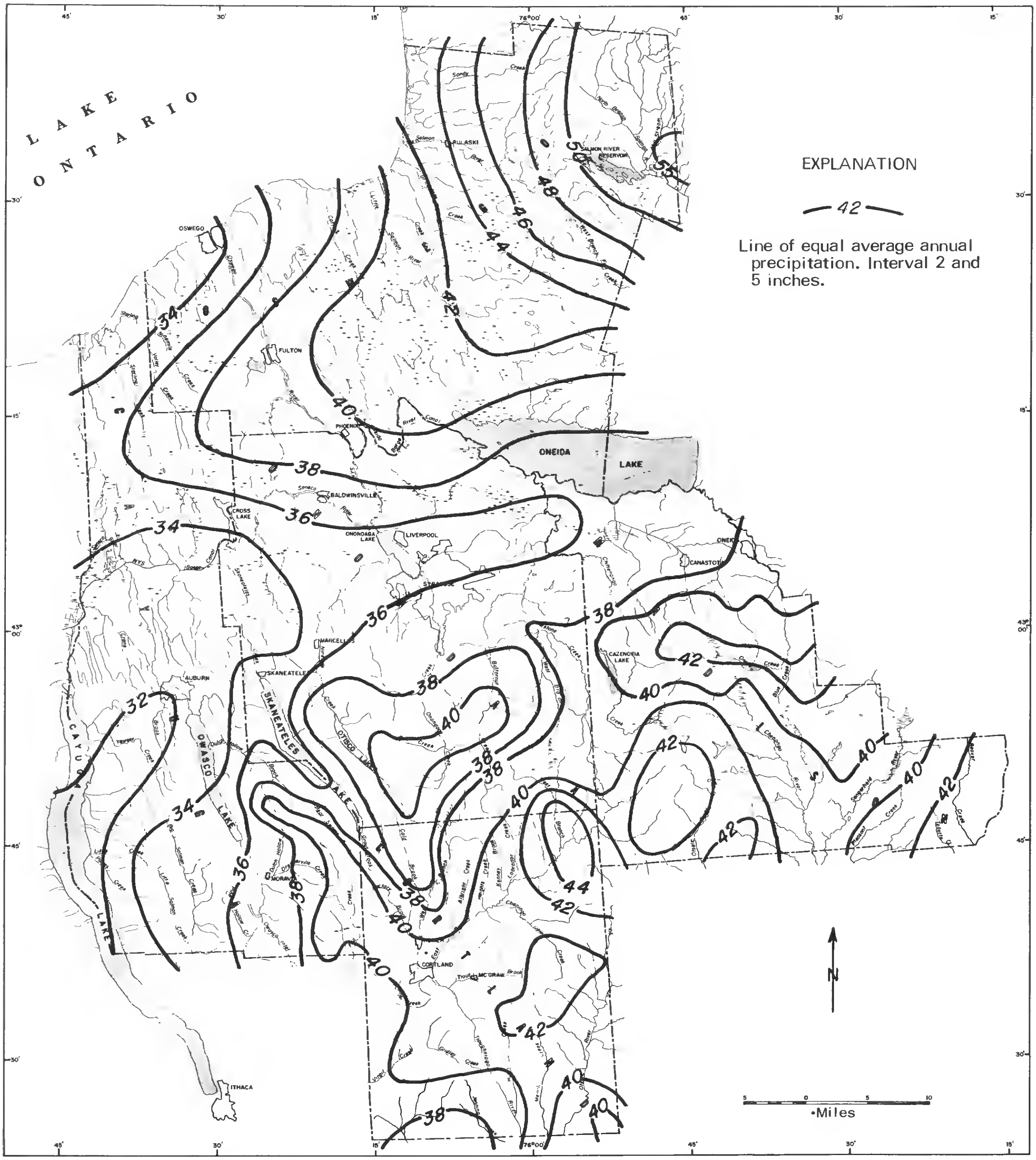

Figure 2.--Average annual precipitation. (Adapted from Knox and Nordenson, 1955, and U.S. Weather Bureau, written commun., 1964.)

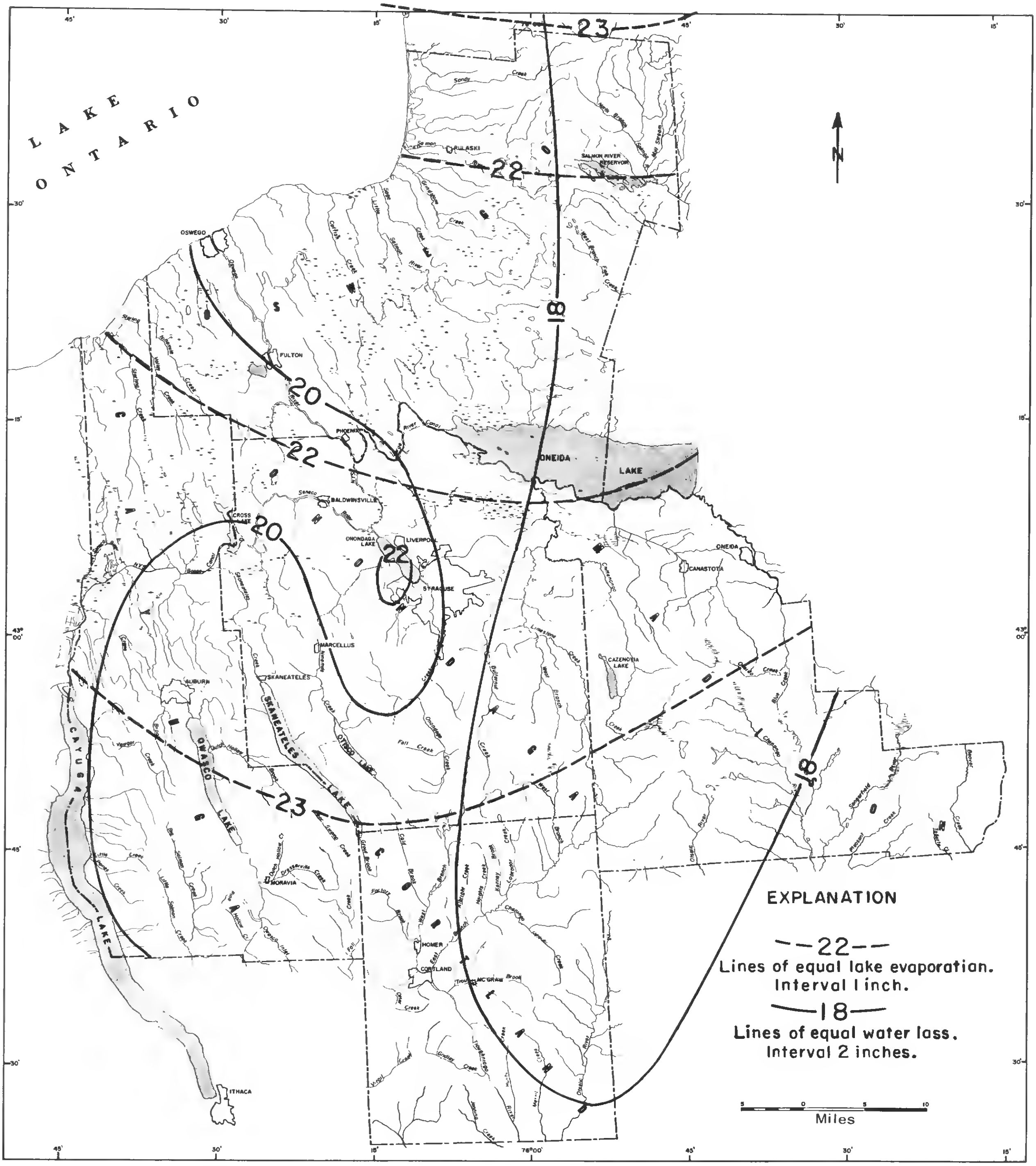

Figure 3.--Average annual lake evaporation and water loss. (From Knox and Nordenson, 1955.)

figure 3. The method used was based on computed pan evaporations. This information may be used for preliminary estimates of expected evaporation from proposed reservoir sites.

The difference between precipitation and water loss is termed water yield. Water yield from a given area includes ground-water flow out of the basin as well as overland runoff. Except on some very small drainage areas, water yield is practically equivalent to streamflow. Average annual streamflow for the Central Region is shown in figure 4 (written communication, Oliver Hunt, 1968). The runoff is shown in cfsm (cubic feet per second per square mile) which can be converted to inches of runoff a year by multiplying by 13.57. It ranges from slightly less than 1 cfsm in central Cayuga County to just over 2.6 cfsm on the Tug Hill Upland. Most of the streamflow occurs from December through May, when loss through evapotranspiration is lowest. The highest streamflow is in March and April when the snowpack melts and the soil-moisture requirements have been satisfied.

A water budget frequently is useful in tracing the movement of water in an area and in determining the availability of water for development. The water budget can be expressed as: $P = R + ET + \Delta S$

in which P = precipitation
R = runoff
ET = evapotranspiration
ΔS = change in water in storage (soil moisture, lakes, reservoirs, snowpack, and ground water).

Unless an intensive study has been made, it usually is not possible to get accurate values for all of these parameters, and certain assumptions must be made. For the two water budgets prepared as part of this study, it was assumed that the moisture capacity of the soil is 4 inches. There is no long-term change in water in storage ($\Delta S = 0$), and the precipitation recorded is less than the actual precipitation that fell on the entire watershed. Judging from numerous other studies, 4 inches of soil moisture seems to be a fairly good average value, and its use should not introduce any serious errors. There is no indication of any long-term trend in either the ground-water level or the runoff in the area, so the assumption of no change in storage is valid. Figure 2 shows that the average annual precipitation is greater in the upper parts of the drainage basin than it is at the stations used for the analyses. The potential evapotranspiration for each area was calculated according to the method described by Thornthwaite and Mather (1957), and was then adjusted to the available moisture to estimate the actual evapotranspiration. In this method it is assumed that any available moisture (precipitation, soil moisture, etc.) goes first to satisfy the demands of potential evapotranspiration. Any excess then goes into runoff and/or storage. If there is not sufficient moisture available to meet the potential evapotranspiration, then actual evapotranspiration equals the amount of moisture available. This method is not very accurate for short periods, such as a day or a week, but is believed reasonably accurate when used on a monthly or yearly basis.

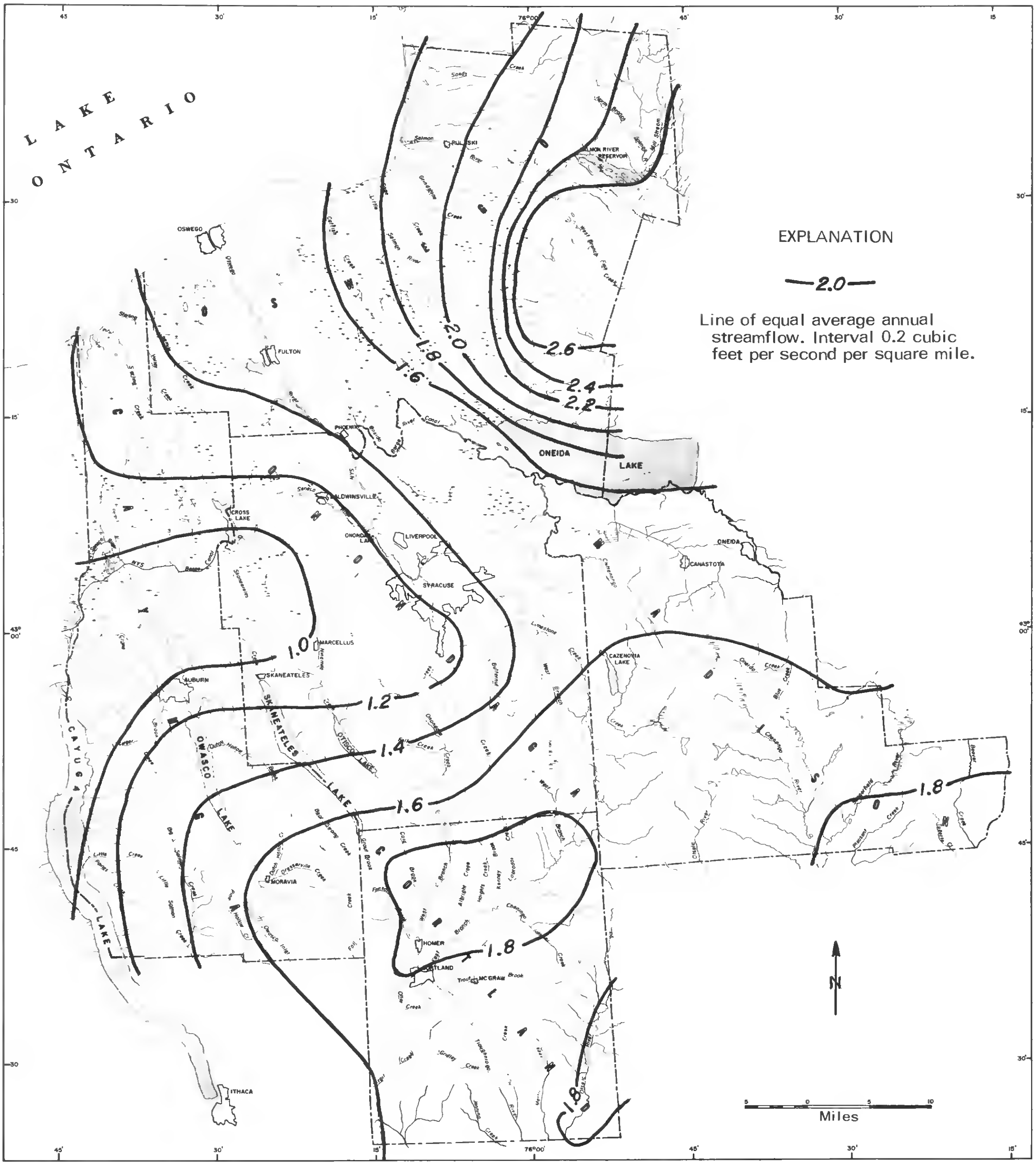

Figure 4.--Average annual streamflow. (Based on records for 1931-60. To convert to inches, multiply by 13.574.)

Figure 5 shows the average annual water budget for the Syracuse area. It is based on the precipitation recorded at the Syracuse airport from 1958 through 1966, and on the runoff measured in Butternut Creek near Jamesville from 1959 through 1966. The average annual precipitation for this period was 33.71 inches, the average annual runoff was 18.16 inches, and the average annual evapotranspiration was estimated to be 20.34 inches as compared to a calculated potential evapotranspiration of 25.15 inches. The 4.8 inches difference between runoff plus evapotranspiration versus precipitation probably is accounted for by increased precipitation in the upper part of the basin, but may in part be due to errors in measurement. Between October and February there is about 5.9 inches more precipitation than runoff plus evapotranspiration. A part of this excess is made up of water stored on the ground in the form of snow, and a part goes into ground-water reservoirs, to appear later as ground-water discharge in the form of streamflow during the summer months.

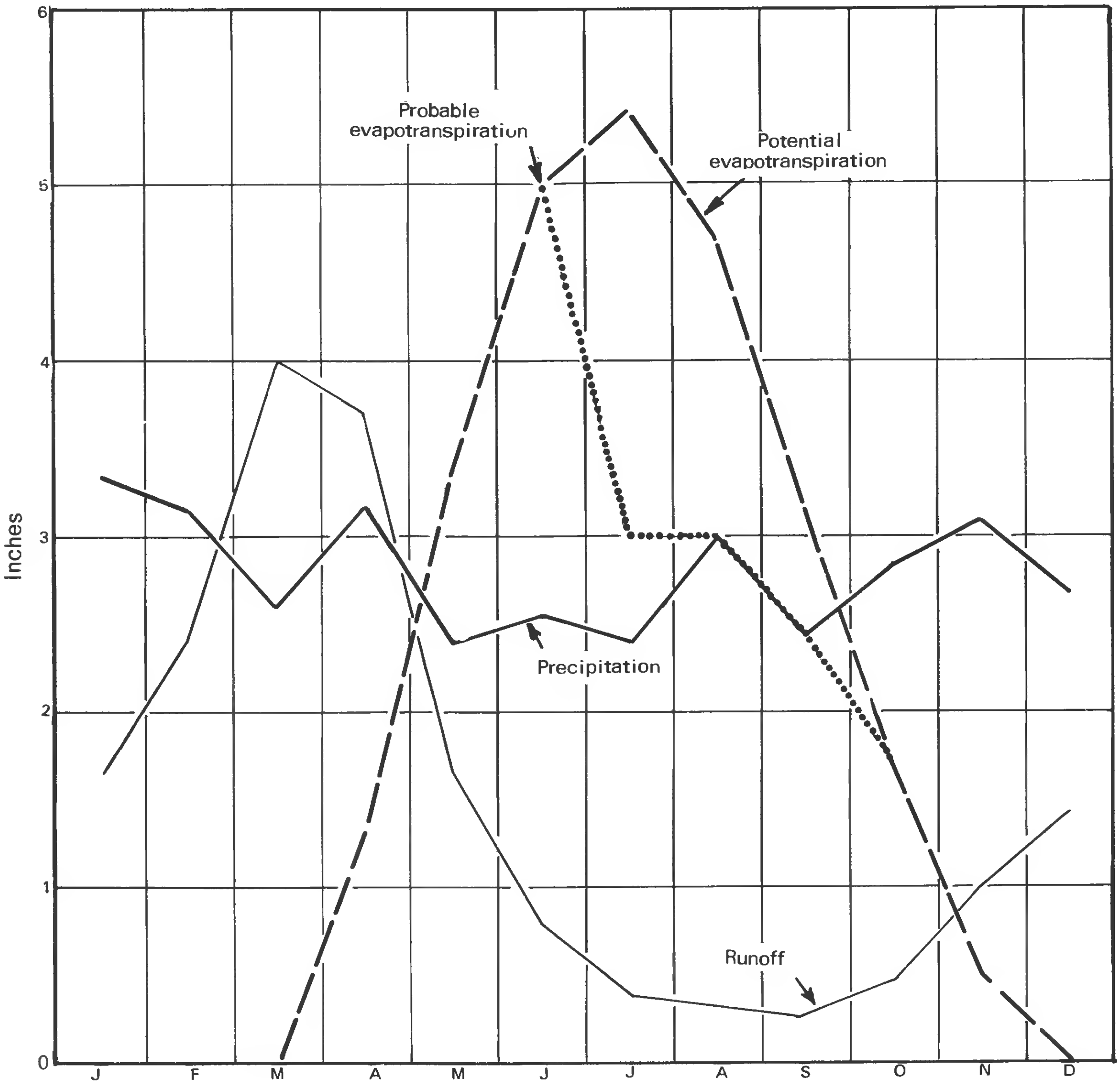

Figure 5.--Water budget for the Syracuse area.

The average annual water budget for the Cortland area (fig. 6) is based on the records of precipitation from 1931 through 1960 and of streamflow from 1939 through 1966, both measured at Cortland. The average annual precipitation was 40.66 inches, the average annual runoff was 21.75 inches, and the average annual evapotranspiration was estimated to be 22.41 inches as compared to a calculated potential evapotranspiration of 24.27 inches. The net deficit of 3.5 inches is again accounted for by greater precipitation in the upper parts of the drainage basin, especially that in the basin of East Branch Tioughnioga River. Between October and February about 5.4 inches of moisture goes into storage.

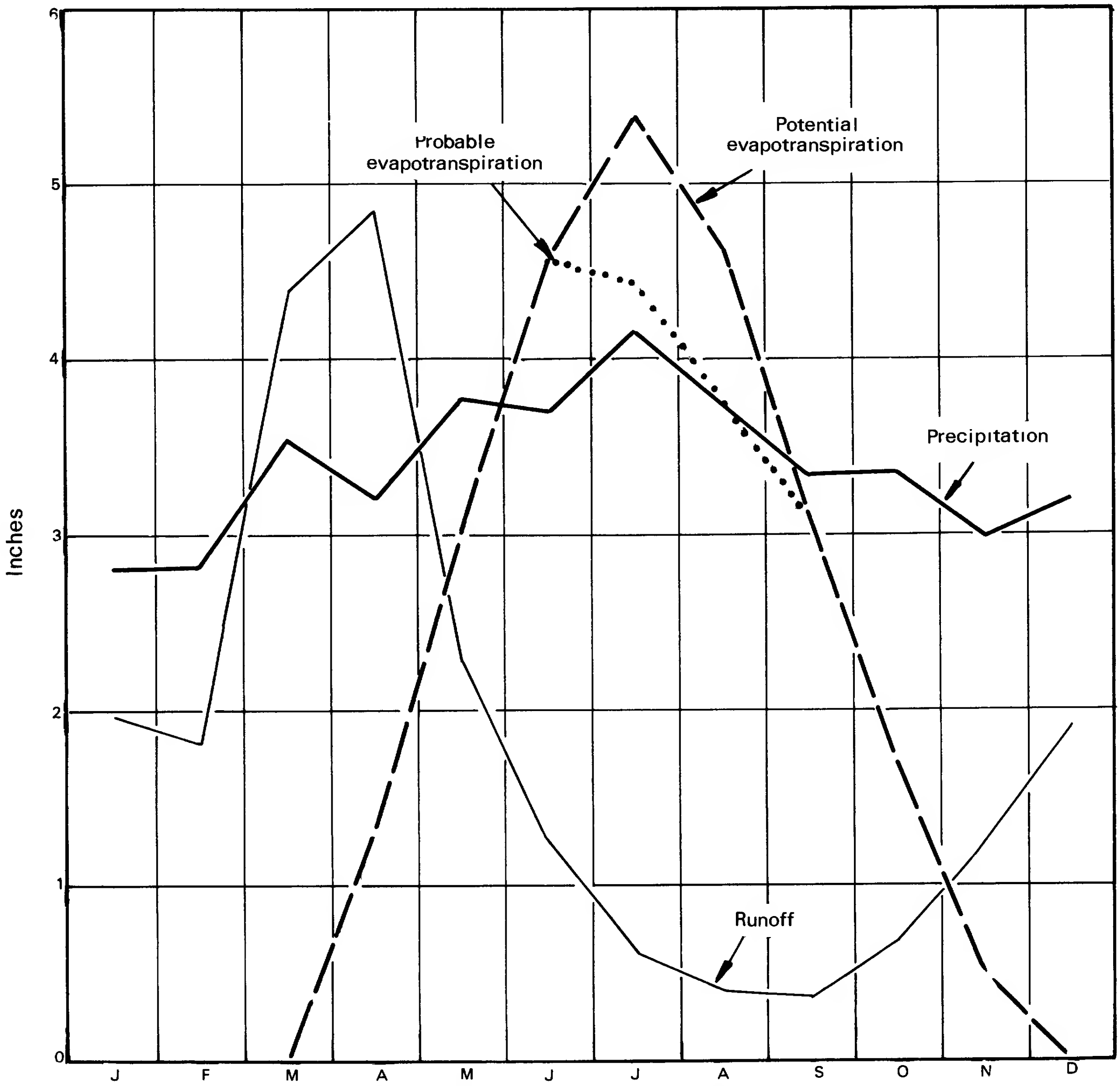

Figure 6.--Water budget for the Cortland area.

Although both these budgets are based on incomplete knowledge of the areas, and several assumptions had to be made, the values given should be of the correct order of magnitude.

WATER USE

Approximately 740,000 people living in the Central New York Region use an estimated 310 mgd (million gallons per day) of water; this includes both domestic, industrial, and other nonresidential uses, but does not include water used for power generation and the operation of the Barge Canal system. If hydroelectric power generation is included in the total, the amount is well over 1 billion gallons per day. Still, this figure represents only about 20 percent of the average daily replenishable supply of water in the five-county area. Also, most of the water is used in a nonconsumptive way. That is, most of the water used is returned to or near the point of withdrawal with little or no change in amount. Thus, it is available for reuse, providing the quality remains satisfactory.

Broadly speaking, water supplies come from two sources: (1) surface water (streams, lakes, and reservoirs); and (2) ground water (wells and springs). Of the total water used in the area (not counting power generation), about 90 percent comes from surface sources, and only about 10 percent from ground sources. The following table summarizes the use of water in the region, based on the latest available data. The information on public water supplies was taken from an inventory made by the U.S. Public Health Service (1964).

Estimated use of water, exclusive of power generation, in the Central New York Region during 1963

Source of water	Estimated average annual withdrawals (million gallons per day)			
	Public supplies	Domestic supplies	Industrial and commercial supplies	Total
Surface water	81	0	200	281
Ground water	12	7	8	27
Both	2	-	--	2
All	95	7	208	310

The types of supplies are separated into:

1) public supplies -- water supplied to home, industrial, and commercial users by municipally- or privately-owned systems;

2) domestic supplies -- water supplied to a single home by an individually-owned system; and

3) industrial and commercial supplies -- water supplied to a factory or commercial establishment by a company-owned system.

Approximately 82 percent of the residents of the Central New York Region are served by a public water-supply system (fig. 7). Lines in figure 7 connect those communities and areas that obtain their water from a larger community or water authority. Dashed lines are used for those areas that obtain water from the Onondaga County Water Authority, which is plotted on the map at Otisco Lake, its source. Starting in 1968, the Onondaga County Water District began withdrawing water from Lake Ontario and providing it on a wholesale basis as an additional supply to both the Onondaga Water Authority and the city of Syracuse. The other sources of supply for these two entities are Otisco Lake and Skaneateles Lake, respectively. This system is not shown in figure 7.

The city of Syracuse is by far the largest water user in the region. It withdraws an average of 42 mgd of water from Skaneateles Lake for public supply. The amount of water used in the city by industry is not precisely known, but it is at least 200 mgd and it may be closer to 500 mgd. Other public water-supply systems in the region which use over 1 mgd are Oswego, Fulton, Auburn, Cortland, East Syracuse, Oneida, Baldwinsville, and the Onondaga County Water Authority.

The use of water for public supplies has generally increased. Of the 40 public supplies for which data on water use are available, 24 showed increased use between 1958 and 1963 (the last year for which use figures are available), and 10 showed decreased use. Table 1 summarizes the use of water by the 14 largest public-supply systems (ones that used at least 500,000 gpd in 1963).

The amount of water used for domestic supplies was estimated by allowing 50 gallons per day for each resident not served by one of the public supplies.

Water used for irrigation has been negligible in the past, but is likely to increase greatly in the near future. Although complete information is lacking, it is not likely that the total amount of water currently used for irrigation exceeds 2 mgd over the frost-free period.

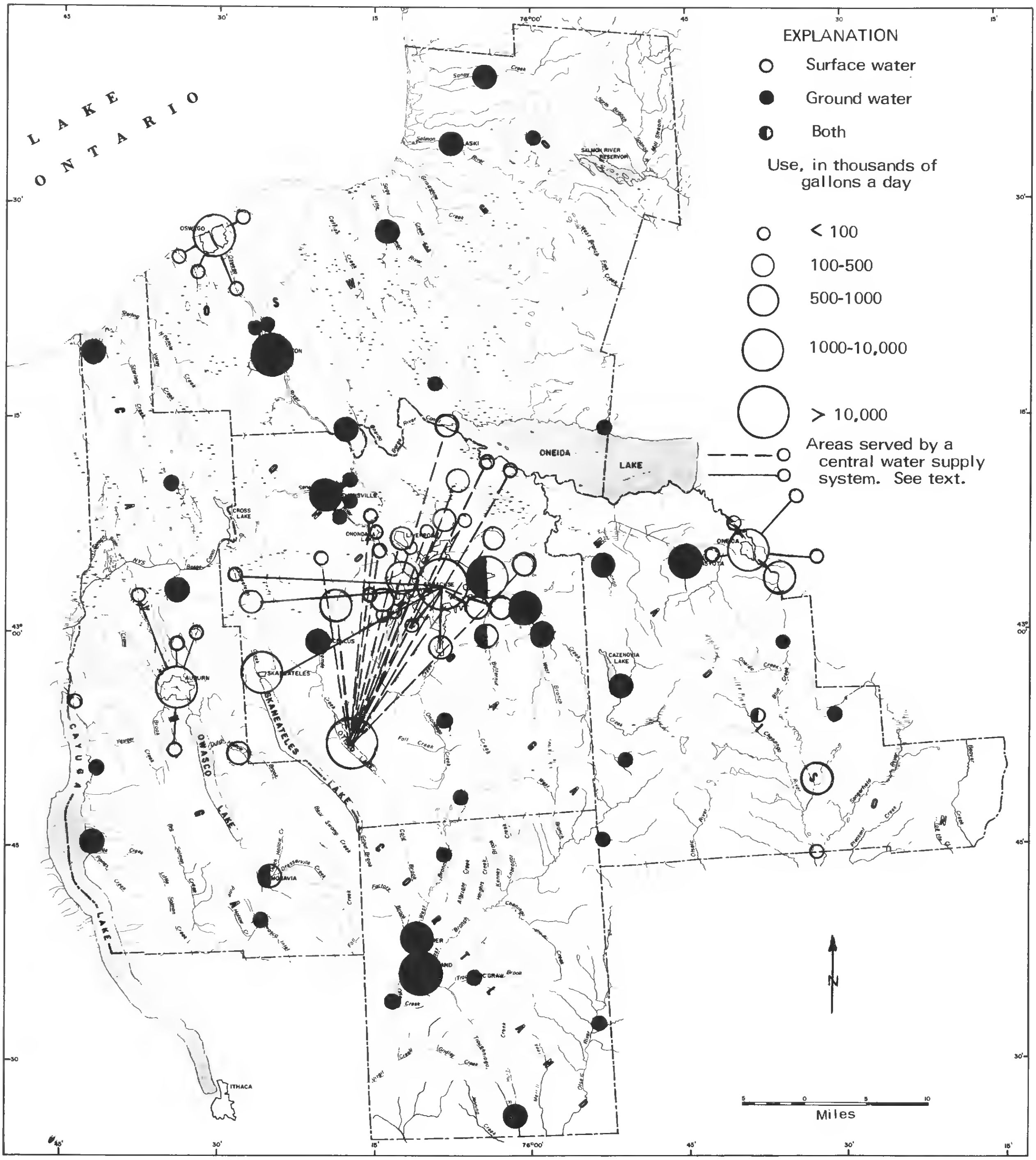

Figure 7.--Location and size of public water-supply systems.

Table 1.--Water use, in thousands of gallons a day

Water-supply system	Source (1963)	1929	1940	1948	1954	1958	1963
Auburn	Owasco Lake	5,250	5,250	6,500	6,500	9,500	8,550
Cortland	Wells	1,740	1,400	2,500	2,500	2,500	3,300
Homer	Wells	200	200	410	500	500	525
Canastota	Wells	275	300	300	600	600	900
Hamilton	Woodman Pond	110	225	400	400	400	550
Oneida	Florence Creek	1,200	1,600	1,600	1,600	1,600	1,600
Baldwinsville	Wells	430	430	430	500	300	1,000
East Syracuse	Wright Brook, springs	800	500	300	500	1,100	1,200
Fayetteville	Springs and wells	50	60	60	60	450	750
Onondaga County Water Authority	Otisco Lake	5,000	7,000	7,500	13,000	14,000	19,350
Syracuse	Skaneateles Lake	24,760	32,000	35,000	42,900	42,900	41,600
Fulton	Wells	1,000	750	750	1,300	1,300	2,000
Mexico	Wells	100	70	80	80	504	500
Oswego	Lake Ontario	5,000	5,000	5,000	5,000	6,000	9,000

GROUND WATER

There are basically two types of water-bearing deposits in the Central New York Region: (1) consolidated deposits (bedrock), and (2) unconsolidated deposits. Although ground water is available practically any place in the region, large supplies (500 gallons per minute or more) are obtained mainly from the coarser, more permeable unconsolidated deposits.

WATER FROM THE BEDROCK

At least 20 different bedrock formations occur in the region, but they can be lumped into 7 hydrologic units on the basis of similarity of lithology and water-bearing properties. These hydrologic units occur as successive east-west bands across the region, as shown in plate 2. The lower shale unit (unit 1) is the oldest, and underlies the entire area. It is overlain by the sandstone unit (unit 2), and the other units, which appear successively to the south through the region. Because all of the beds dip gently to the south, each unit is overlain by progressively thicker amounts of the younger units as you go south, as shown by the cross section in plate 2.

The hydrology of the bedrock is summarized in table 2. Although sufficient water for household use can be obtained from all of the hydrologic units, only the dolomite, middle shale, and limestone units (units 4, 5, and 6 in plate 2) are apt to supply large quantities of water to wells. As is apparent from the table, obtaining water from any of the bedrock units depends on the well penetrating water-bearing joints or bedding planes. It is not always possible to predict the location of these openings, which explains why one well may be dry or may yield very little water, and a nearby well has abundant water and may not be as deep. Large yields are obtained where a well penetrates one or more solutionally enlarged joints or bedding planes.

Because much of the bedrock is soluble, water from wells tapping bedrock is likely to contain large amounts of dissolved solids, salt, and/or sulfate, and may be very hard. This is especially true of water from wells tapping hydrologic units 4, 5, and 6 (pl. 2). In places, water from these units is too highly mineralized for any use except cooling, fire protection, or sanitation. The section on the quality of water contains more detailed discussion of the mineral contents of the water from the various aquifers.

WATER FROM THE UNCONSOLIDATED DEPOSITS

Throughout most of the study area, the bedrock is overlain by unconsolidated deposits of gravel, sand, silt, and clay, and various mixtures of these materials. These deposits range in thickness from a thin veneer on some of the uplands to as much as 290 feet in the major valleys. They can be divided into coarse-grained deposits (sand and gravel), fine-grained deposits (fine

Table 2.--Summary of the bedrock hydrology

Geologic rock unit	Description	Hydrologic unit (See plate 2)	Average thickness (feet)	Water-bearing characteristics
West Falls Formation	Black and gray shale, gray siltstone and sandstone; calcareous concretions and nodules.	Upper shale (7)	2,200	Water occurs along joints and bedding planes; possibly also in intergranular pore spaces in some sandstones. Yields as much as 100 gpm, average 6-10 gpm.
Sonyea Formation	Olive-gray to black shale.			
Genesee Formation	Black and gray shales; some thin sandstone layers.			
Tully Limestone	Black limestone.			
Hamilton Group	Black shales, calcareous shales; thin limestone layers.			
Onondaga Limestone	Blue-gray, massive limestone.	Limestone (6)	340	Water occurs along joints and bedding planes; some openings have been enlarged by solution of carbonates and gypsum. Yields as much as 700 gpm, average 16-25 gpm.
Manlius Limestone	Dark blue, thin-bedded limestone.			
Rondout Limestone	Gray, shaly dolomite.			
Cobleskill Limestone	Gray limestone and dolomite.			
Bertie Limestone	Gray dolomite, some thin shale partings and layers of gypsum.			
Camillus Shale	Gray, thin-bedded shale; beds of gypsum, salt and dolomite.	Middle shale (5)	850	Water occurs along joints and bedding planes; some openings have been enlarged by the solution of gypsum and salt. Yields as much as 300 gpm, average 25 gpm.
Vernon Shale	Red, soft shale, beds of green shale, gypsum and dolomite.			
Lockport Dolomite	Dark-gray dolomite.	Dolomite (4)	150	Water occurs along joints and bedding planes; some openings have been enlarged by solution of carbonates. Yields as much as 300 gpm, average 50 gpm.
Clinton Group	Alternating layers of red and green shale and sandstone; some thin beds of limestone.	Sandstone and shale (3)	250	Water occurs along joints and bedding planes. Yields as much as 30 gpm, average 5 gpm.
Albion Group (may include equivalent of Queenston Shale)	Red, fine- to coarse-grained, massive sandstone.	Sandstone (2)	500	Water occurs along joints and bedding planes; possibly also in intergranular pore spaces. Yields as much as 125 gpm, average 10 gpm.
Oswego Sandstone	Gray, fine-grained sandstone.			
Utica Group	Black and gray shale.	Lower shale (1)	800	Water occurs along joints and bedding planes. Yields as much as 5 gpm, average 3 gpm.

sand, silt and clay), and till (a mixture of clay, silt, sand, gravel, and even boulders, that was laid down by the glacier).

Till is the widest spread of the unconsolidated deposits. It covers most of the upland, a large part of the lowland south of Lake Ontario, and underlies other unconsolidated deposits in much of the rest of the area. The till is about 50 feet thick on hilltops, 30 to 40 feet thick on gentle slopes, and is much thinner or absent on steep slopes. In the lowland the till generally is about 30 feet thick, but in places it may be as much as 200 feet thick.

Till is not a good water-bearing deposit. It contains so much fine-grained material that it has a very low permeability and transmits water poorly. It usually is necessary to construct a large-diameter dug well to obtain enough water for household use. Rarely, if ever, is it possible to obtain more than 3 gpm (gallons per minute) from till.

The fine-grained deposits were laid down chiefly in lakes that formed at the edge of a melting glacier. These deposits are found in the valleys and in parts of the lowlands, particularly in the Oneida Lake area. Like the till, the clay and silt are not good water-bearing deposits, and yields from wells tapping them rarely exceed 1 or 2 gpm.

The main source of water for large-yielding wells in the Central New York Region is the coarse-grained deposits, which are found principally in the valleys and in scattered deposits in the lowland. They were laid down as deltaic deposits by streams flowing into the glacial lakes, either from the glacier or from adjacent highlands; as channel deposits by streams flowing under the glacier, away from the glacier, or out of the lakes; and as terrace deposits by streams flowing between glacial ice and the sides of a valley.

Yields of 500 gpm or more generally can be obtained from well-sorted sand and gravel deposits that have a saturated thickness of 40 feet or more. This is particularly true of the Homer-Cortland area, where at least 11 wells are reported to yield 500 to 4,000 gpm. Wells yielding over 500 gpm have also been reported in Syracuse and near Jacks Reef at the southern end of Cross Lake. Many other wells tapping sand and gravel in the region are reported to yield from 100 to 500 gpm.

In many places in the region, the fine-grained deposits (particularly the lake-deposited silt and clay) overlie coarse-grained deposits that can yield large quantities of water to wells. Although large yields are obtained initially, the fine deposits may prevent or delay recharge to the coarse deposits, and long-term yields may be disappointing. But where the coarse deposits are readily recharged, they usually are capable of yielding large quantities of water to wells indefinitely.

Recharge to the deposits may occur directly from precipitation, by infiltration from streamflow (which may be increased through pumping), and by artificial means such as water-spreading and recharge wells. Direct recharge from precipitation occurs mainly where the land surface is fairly coarse-grained permeable material that allows the water to infiltrate rapidly.

Recharge from streamflow occurs mainly during spring runoff when the water table is lowest, and the higher flows tend to scour the stream channel, removing the fine material and increasing the permeability. The amount of water entering the aquifer in this manner can be increased, with an accompanying decrease in the water lost to runoff, through what is termed "induced recharge." When developing an aquifer that is in hydraulic contact with a stream, it is advisable to locate the wells where their cones of depression will extend to the bed of the stream. By thus dewatering the aquifer under the stream, more water from the stream is able to enter the aquifer. Induced recharge has been discussed in greater detail by Reed and others (1966) and by Winslow and others (1965).

There are several methods for artificially recharging an aquifer, including diverting streamflow over an area of permeable materials, using pits or wells to put the water into the aquifer, and scarifying the streambed to increase its permeability. Todd (1959) has reviewed most of the work on artificial recharge that had been done prior to 1955, and much of the more recent work has been described in the literature (Parker and others, 1967). The method chosen depends on the individual site. Diversion and spreading of streamflow requires a fairly large area, and usually is not practical in heavily developed areas, or in areas where land is expensive. Recharge wells and pits require special construction, and although they generally recharge lesser quantities of water than are possible using spreading grounds, they may be the only practical means in places; Peoria-type pits (Suter, 1956; Smith, 1967) may well be the most practical type for use in the Central New York Region. In some areas it may be possible to utilize abandoned gravel pits for artificial recharge.

DEVELOPMENT OF GROUND-WATER RESOURCES

In a summary report such as this, lack of space and time forbids the discussion in detail of the various areas that have a potential for yielding large quantities of ground water. Figure 8 shows those areas in the Central New York Region where there is a strong possibility of obtaining 500 gpm or more from properly constructed and developed wells. Most of these areas are sand and gravel deposits along the major streams, particularly in the southern part of the area. The deposits generally are in good hydraulic connection with the streams, which is another reason for their large yields.

Unfortunately, most of the areas where large yields are possible in the northern half of the region are also areas where the quality of the water may present a problem. Figure 1 shows the areas in the region where water problems exist. Although not suitable for most domestic purposes, much of this poor-quality water could be used for purposes for which the quality is not too important, such as: sanitation, cooling, fire protection, and, in some cases, feeding boilers.

Present development of ground water in the Central New York Region is very small compared to the total amount available. Figure 9, which was adapted from a U.S. Geological Survey map of New York State prepared by Irwin Kantrowitz, shows the estimated potential daily yields of the better

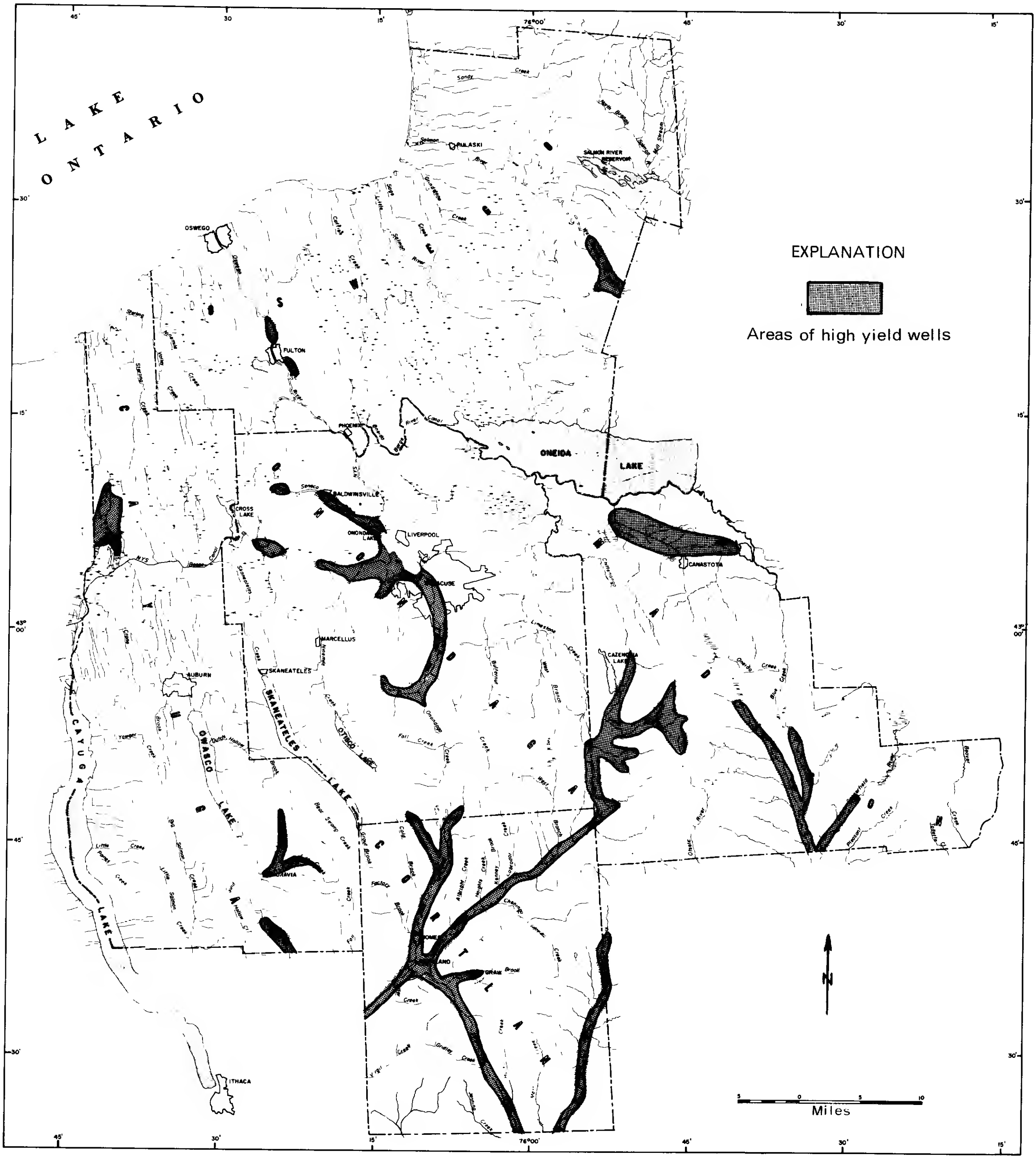

Figure 8.--Areas where wells yielding 500 gallons per minute or more can be developed.

sand and gravel aquifers in the region, assuming complete development of the aquifers. These estimates are based on available data, and should be treated as indications of yield rather than actual values. Some of the aquifers extend into the adjoining counties, and the estimated yields are for the entire aquifer. A rough estimate from the map indicates that at least 240,000,000 gallons a day can be obtained from these aquifers, compared to an estimated present use of 27,000,000 gallons a day from all ground-water sources.

There do not seem to be any areas at present where the ground water has been overdeveloped, and it is very likely that many more good wells can be obtained in the areas of present ground-water use. In addition, new development can take place along the areas shown in plate 2 and figure 9. Many of the smaller communities presently obtain their water from wells and springs. In most cases these supplies can be increased to meet future demands, and other communities, which are favorably located, will want to develop the local ground water as a source of their water.

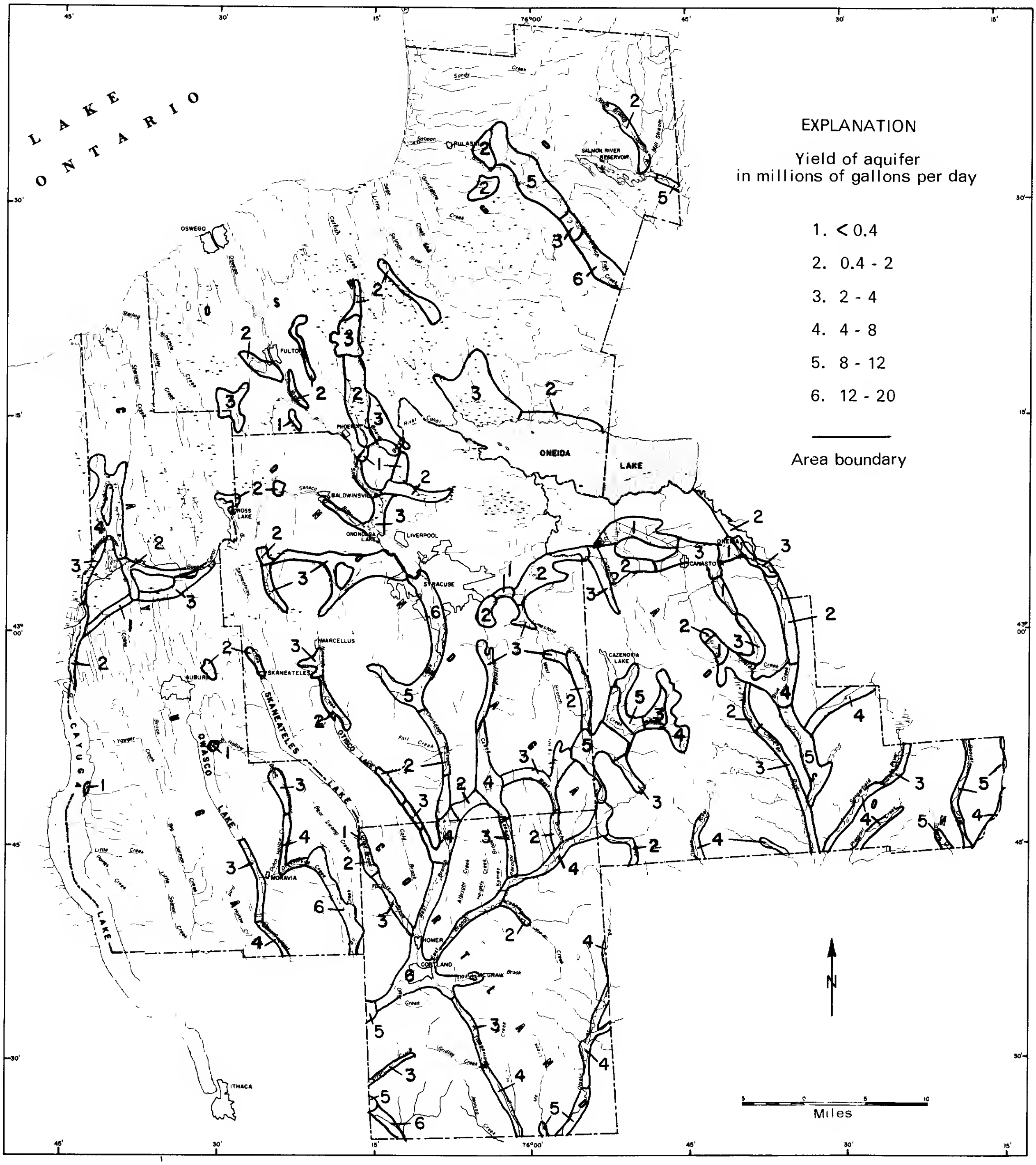

Figure 9.--Availability of ground water from sand and gravel deposits.

SURFACE WATER

The Central New York Region is drained by four major stream systems, the Susquehanna River, the Oswego River, the Mohawk River, and streams tributary to Lake Ontario (pl. 1). Although the total area of the five-county region is only 3,622 square miles, it receives water from more than 6,500 square miles of drainage area. If Lake Ontario is included, it may be said that the Central Region has water available from almost 300,000 square miles of drainage.

The Oswego River basin dominates the drainage, covering about 56 percent of the region. Next is the Susquehanna River basin, which drains most of Cortland County, parts of Madison and Onondaga Counties, and an insignificant part of Cayuga County, amounting to about 25 percent of the study area. Streams tributary to Lake Ontario drain about 19 percent of the region, and the Mohawk accounts for a scant 0.5 percent, all located in eastern Madison County.

The lakes of the region are its most striking physical feature. Four of the famous Finger Lakes - Cayuga, Owasco, Skaneateles, and Otisco lie wholly or in part within the five-county area. Other major lakes in the region are Oneida and Onondaga. One of the Great Lakes, Lake Ontario, forms the northern border of the area. As much as 6 percent of the Oswego River basin is taken up by lakes, and the percentage for the Central New York Region as a whole is about as high.

These lakes are of great economic and recreational value to the people of the area. Many communities use them for water supply. Several lakes offer excellent fishing: Oneida Lake is famous countrywide for its walleyes, while lake trout attract many anglers each year to Cayuga Lake.

With the exception of Onondaga Lake, the lakes in the region are generally free from serious manmade pollution and their quality ranges from fair (eutrophic Oneida Lake) to excellent (Skaneateles Lake). Onondaga Lake receives large amounts of chemical, organic, and bacterial pollution from the Syracuse area.

One of the most important water resources of the region is the New York State Barge Canal. Built primarily for navigation, the canal now serves several other important functions as well, including irrigation, recreation, and flood control. A brief description of the complex canal system follows.

The canal (pl. 1) enters the Central New York Region while crossing Oneida Lake, and then merges with the Oneida River before reaching the beginning of the Oswego River at Three Rivers. From there it proceeds north as the Oswego River to the city of Oswego and Lake Ontario; and south and then west from Syracuse following the Seneca and Clyde Rivers to Lyons, west of the study area.

The water supply for this complex canal system between Lyons and Three Rivers is obtained from Canandaigua, Seneca, Cayuga, and Oneida Lakes. Water, in limited quantity, is also received from the Susquehanna basin via

Erieville and DeRuyter Reservoirs. The summit level at Rome is supplied from the Black and Mohawk River basins. The Oswego branch of the system uses the Oswego River between Three Rivers and Oswego. A short branch uses Onondaga Lake Outlet and Onondaga Lake to reach a terminal at the mouth of Onondaga Creek at the eastern end of Onondaga Lake at Syracuse. The Cayuga and Seneca branch uses the Seneca River upstream from the junction with the Clyde River, and Seneca Lake to reach Geneva and Watkins Glen. A branch in Cayuga Lake and a terminal in Cayuga Inlet serve Ithaca.

STREAMFLOW CHARACTERISTICS

Streamflow is highly variable with respect both to time and place. Floodflows are commonly thousands of times greater than low flows, and average flows may range areally from less than 1 to more than 2 cfs (cubic feet per second) per square mile.

Most often, it is the extremes of flow which cause or accentuate water problems such as floods, water shortages, and pollution. The following discussions deal with variations in streamflow within the Central New York Region and present streamflow characteristics useful to water managers in solving these problems.

VARIABILITY OF STREAMFLOW

Streamflow varies in two ways. It varies from time to time at a given location and it varies also from location to location. The variations with time at a given location are directly or indirectly due to changes in the weather; that is, they are due to variations in precipitation intensity and duration, air temperatures, relative humidity, and other less significant meteorological factors. Variations in streamflow with geographic location are due largely to differences in climate, topography, and geology, and also to differences in the weather.

Day-to-day variations in the flow of streams appear to be random, without a clearly definable trend. However, when the flow of a stream is represented by monthly averages, a yearly cycle becomes apparent, with flows usually highest in March, April, and May, and lowest in July, August, and September.

The yearly streamflow cycle shown in figures 5 and 6 is typical of most streams in this region and the humid northeastern United States in general. When the growing season ends, usually in the beginning of October, the use of water by plants lessens drastically and streamflow increases as more water becomes available. During the winter months, when freezing temperatures prevail, a large part of the precipitation that falls accumulates on the ground as snow and is temporarily unavailable for streamflow. Consequently, stream discharges are composed largely of ground-water contributions. When temperatures rise above freezing in the spring of the year, the combination

of rain and snowmelt often produces the highest discharges of the year. When the growing season begins (usually about the middle of May), vegetation starts to consume much of the precipitation otherwise available for streamflow. Ground-water storage, which has been replenished during the nongrowing season, again makes up most of the streamflow. As ground-water storage is depleted through the summer months, streamflow decreases until the growing season ends. Then, water from precipitation again becomes available to increase streamflow and replenish ground-water storage. Thus, the yearly cycle is completed.

In addition to these within-year variations just discussed, we observe that streamflow varies from year to year. One year we may experience unusually large floods and the next year much smaller ones, or we may experience in 1 year a daily discharge lower than any in the previous 50 years, and the next year the minimum daily discharge may be much larger. Years of drought alternate between years of water abundance, but no one can yet predict in what years they will occur. (Later discussions concerning low flows, high flows, and floods treat these year-to-year variations from a statistical standpoint.)

Often, it is desirable to study the effects on streamflow of factors such as climate, topography, and geology, which do not vary appreciably with time, but which differ from place to place. Day-to-day variations in flow obscure these effects, so that it is necessary to portray streamflow in a manner which reflects long-term flow conditions. One way to do this is through the use of the flow-duration curve, examples of which are shown in figure 10.

We may read, for example, that the flow of Butternut Creek at Jamesville was equal to or greater than 0.15 cfsm (cubic feet per second per square mile) about 98 percent of the days.

Searcy (1959) discusses flow-duration curves at length with regard to their hydrologic significance and applications. With respect to shape, Searcy (p. 22) says, "A curve with a steep slope throughout denotes a highly variable stream whose flow is largely from direct runoff, whereas, a curve with a flat slope reveals the presence of surface- or ground-water storage, which tends to equalize the flow. [In other words, the presence of storage tends to produce a flat slope at both ends of the curve.] The slope of the duration curve shows the characteristics of the perennial storage in the drainage basin; a flat slope at the lower end indicates a large amount of storage, and a steep slope indicates a negligible amount. Streams whose high flows come largely from snowmelt tend to have a flat slope at the upper end. The same is true for streams with large flood-plain storage or those that drain swamp areas."

Notice, from figure 10, the manner in which the duration curves fan out at the lower end. From the preceding discussion, it is expected that this should be revealing of different storage characteristics among the four streams. Chittenango Creek, for example, shows a flatter slope at the lower end than does Butternut Creek. This is probably due to the storage available from Cazenovia Lake and Cedar swamp, which support the flow of Chittenango Creek during dry weather. The Butternut Creek basin, on the

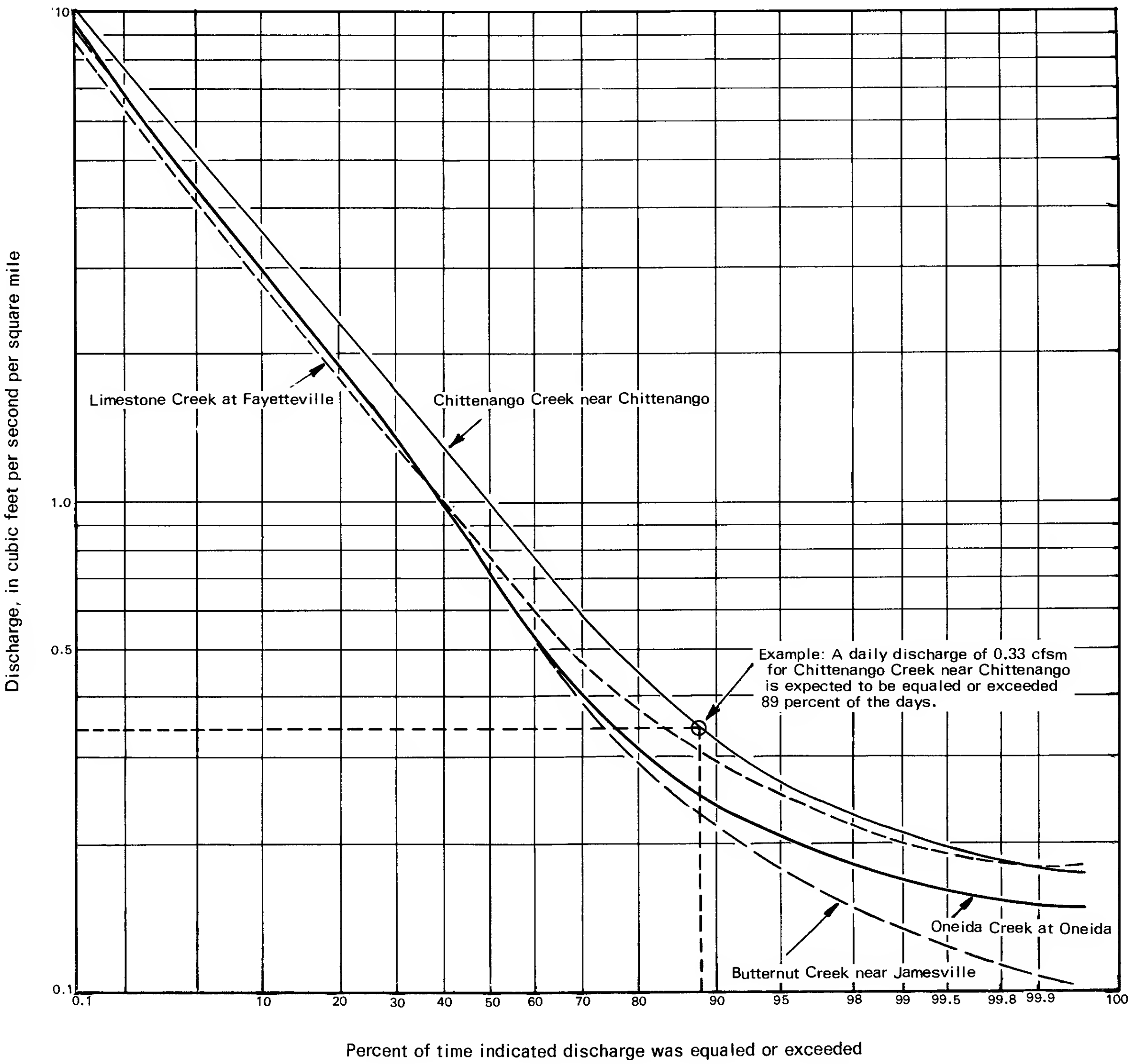

Figure 10.--Duration of daily flows for four streams, adjusted to the 1931-60 water years.

other hand, does not have as much storage available as the Chittenango basin, although fairly extensive well-sorted unconsolidated deposits do yield water to Butternut Creek in dry weather.

Flow-duration data for streams in the study area are available from several sources. Hunt (1967) presents flow-duration data for the Susquehanna River basin, O'Donnell and Hood (U.S. Geological Survey, written commun., 1967), for the Oswego River basin.

Flow-duration curves, then, are useful in comparing place variations in streamflow due to differences in climate, topography, geology, etc. For specific studies involving the quantitative determination of flow characteristics, other types of analyses are more meaningful. These include low- and

high-flow frequency curves, flood-frequency relations, flood-volume-frequency relations, and draft-storage-frequency data. The following discussions present this information for the Central New York Region or refer to reports where it is available.

LOW STREAMFLOW

In planning for water supply and waste dilution, the question often arises whether the flow of a stream will be sufficient at all times for its intended purposes. It is almost always desirable in studies of this nature to have a knowledge of some of the low-flow characteristics of the stream site in question.

Lowest flows generally occur during the months of August, September, and October, due to the demands of the growing season which have previously taken much of the water otherwise available for streamflow. Areally, the magnitude of the low streamflows depends largely on variations in geology and precipitation (or lack of it). Streams fed by sand or sand-and-gravel aquifers tend to have high sustained flows during dry weather, while those fed from areas underlain by till or shale, through which water moves slowly, have low dry-weather yields.

A useful way to summarize low-flow information is through the low-flow frequency curves, examples of which are shown in figure 11 for Onondaga Creek at Syracuse. For a selected consecutive-day period of 30 days, for example, we read that the minimum average flow to be expected once in an average time interval of 20 years is 12.5 cfs.

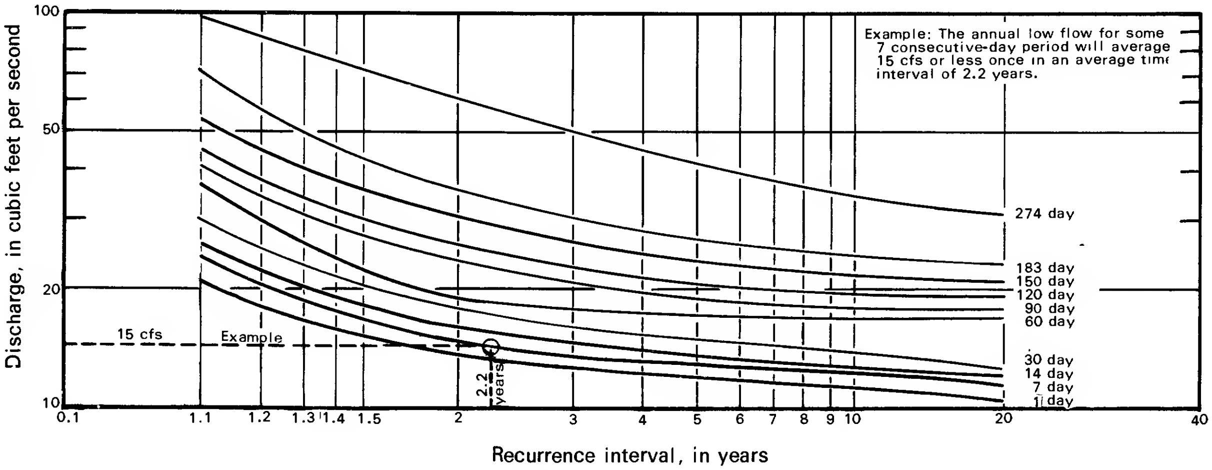

Figure 11.--Magnitude and frequency of minimum annual average consecutive-day discharge of Onondaga Creek at Dorwin Avenue, Syracuse, based on climatic years 1952-63.

Frequency curves for 1-, 7-, and 30-day periods are used in studies involving fish stocking, water supply, and waste dilution. Low-flow frequency data for streams in the Susquehanna River basin part of the Central New York Region are available in a published report (Hunt, 1967). Other low-flow frequency data are available in the files of the U.S. Geological Survey in Albany, New York. It is expected that by 1971 there will be comprehensive water-resources investigations covering all major basins of the five-county area.

Figures 12 and 13 show the variations of the 7-day, 2-year and the 7-day, 10-year minimum average consecutive-day flows along streams in the Central New York Region. Only flow ranges are given on the maps, and the information contained on them is most suitable for preliminary studies where only first approximations are required. The 7-day, 2-year flow values are practically equivalent to the median 7-day, annual flows. As such, they may be used in the draft-storage-frequency relationships presented in the next section of this report.

REGIONALIZED DRAFT-STORAGE-FREQUENCY RELATIONSHIPS

Demands for water often are greater than minimum streamflow but can be met by providing reservoir storage. The analysis of storage requirements for a specific project involves the consideration of streamflow characteristics, the geology and the topography at the storage site, the pattern of withdrawal, the economic consequences of a temporary deficiency in water supply, the amount of evaporation from the reservoir, the reduction in capacity because of sedimentation, and the possible modification of the reservoir capacity to provide for flood storage or recreation. This report, however, considers only the streamflow facet of development without dealing with the suitability of a given site in other respects.

The method of analysis used in this report is based on within-year storage required to sustain various draft rates continuously. Constant draft rates are superimposed on daily discharges at a gaged site for each year beginning April 1 and ending March 31. A full reservoir is assumed at the beginning of each year. On those days when streamflow is greater than a given draft, a positive storage value accrues. On those days when streamflow is less than the given draft, a negative storage value accrues. A cumulative storage table is thus formed, and, for the given draft rate. the greatest difference between successive high and low values constitutes the storage required to maintain that draft for that year. A check is then made to see if the indicated storage required was replenished at the end of the year. If similar analyses for a number of years show that storage was not replenished consistently, the corresponding draft rates may be too high to be sustained. The process is repeated for various other draft rates for each year of record. From this information a series of draft-storage-frequency relations may be prepared.

O'Donnell and Hood (written communication, 1967) have developed regional draft-storage-frequency relations for the Oswego River basin. These relations are assumed to be applicable also to the remainder of the five-county area not in the Oswego basin. The development of these regional relations depends on successfully relating some streamflow characteristic to draft rates and storage requirements for given recurrence intervals. This was accomplished in the Oswego River basin study by using the median 7-day, annual flow. The resulting relations, for a 20-year recurrence interval, are shown in figure 14 (minimum average 7-consecutive day, 2-year flows, shown on a map in a previous section, may be used in lieu of median 7-day, annual flows).

To use these regional relations for a particular ungaged site, the median annual 7-day, minimum flow must first be estimated from several base-flow measurements that can be correlated to gaged streams. When the estimated median annual 7-day, minimum flow is expressed in terms of cfsm, storages required for draft rates of 0.2, 0.3, and 0.4 cfsm may be read directly from figure 14. Storages for intermediate draft rates may be interpolated.

The theoretical upper limit for a draft rate is the mean annual discharge of a stream. In practice, because of evaporation losses and the impossibility of providing infinite storage, it is recommended that constant draft rates not be larger than the smallest annual mean discharge of record or, if no records are available, the smallest annual mean can be estimated from several discharge measurements and correlations with gaged streams.

It generally is not economical to provide storage in excess of 100 million gallons per square mile of drainage (or about 5.8 inches of runoff). Cross (1963) recommends this figure as an upper limit. However, natural storage is available in some locations which far exceeds this limit. The Finger Lakes, for example, have large natural storages in relation to their drainage areas.

The U.S. Geological Survey is currently conducting a statewide water-resources investigation, one part of which will be to define regional draft-storage-frequency relations which will take into consideration over-year storage. When completed, it will be a distinct improvement over the within-year type of analysis presented in this report, and will enable more sophisticated calculations of storages required for water supply in the Central New York Region.

REGIONAL FLOOD FREQUENCY

Knowledge of the magnitude and frequency of floods to be expected is an invaluable tool in the design and placement of structures over or adjacent to streams. The magnitude and frequency of floods in New York State have been described on a regional basis by Robison (1961); the various curves and relations applying to the Central New York Region are discussed in this section. Dalrymple (1960) gives a detailed description of the methodology and procedures for deriving these curves.

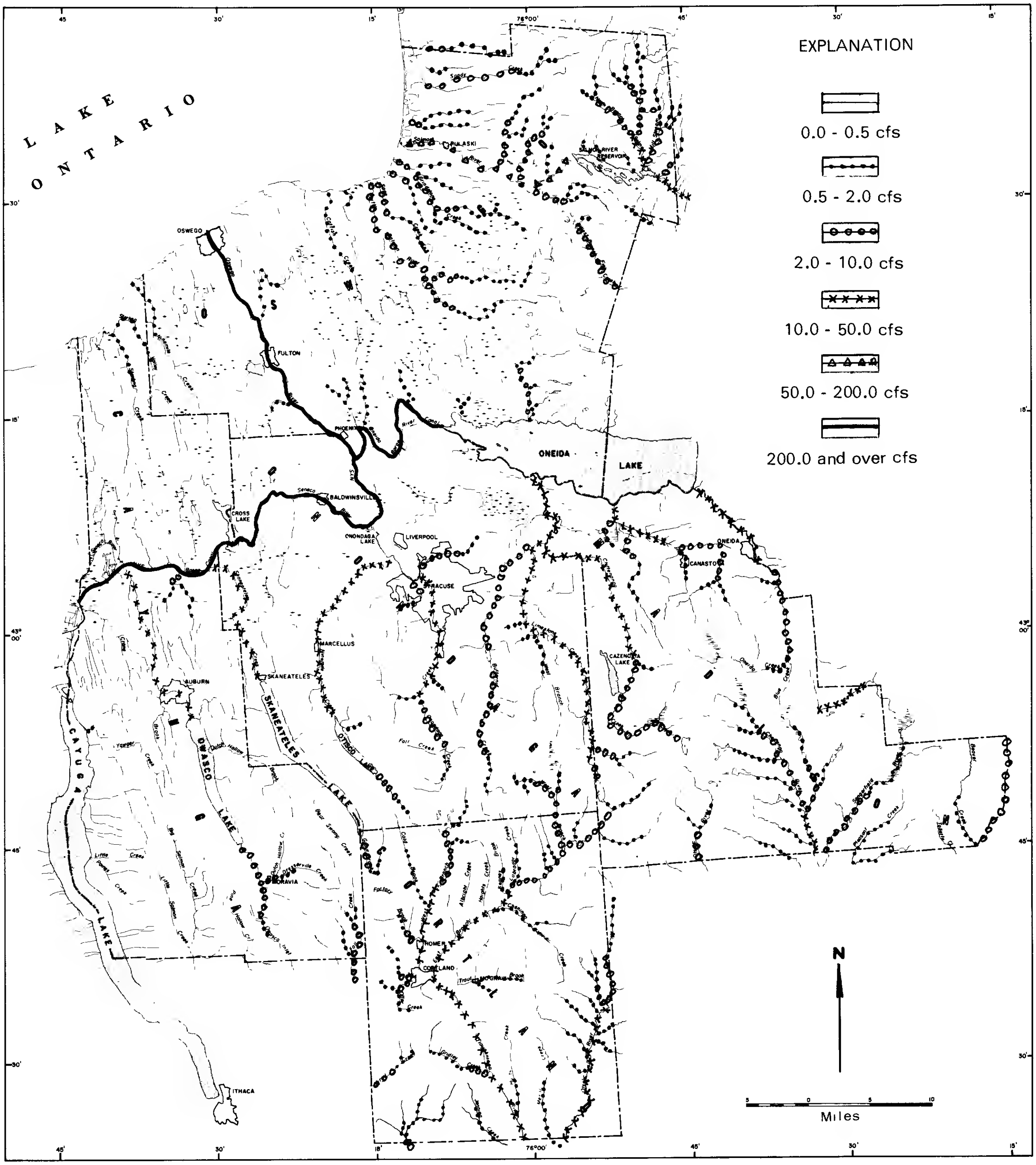

Figure 12.--Minimum average 7-consecutive day flows with a recurrence interval of 2 years.

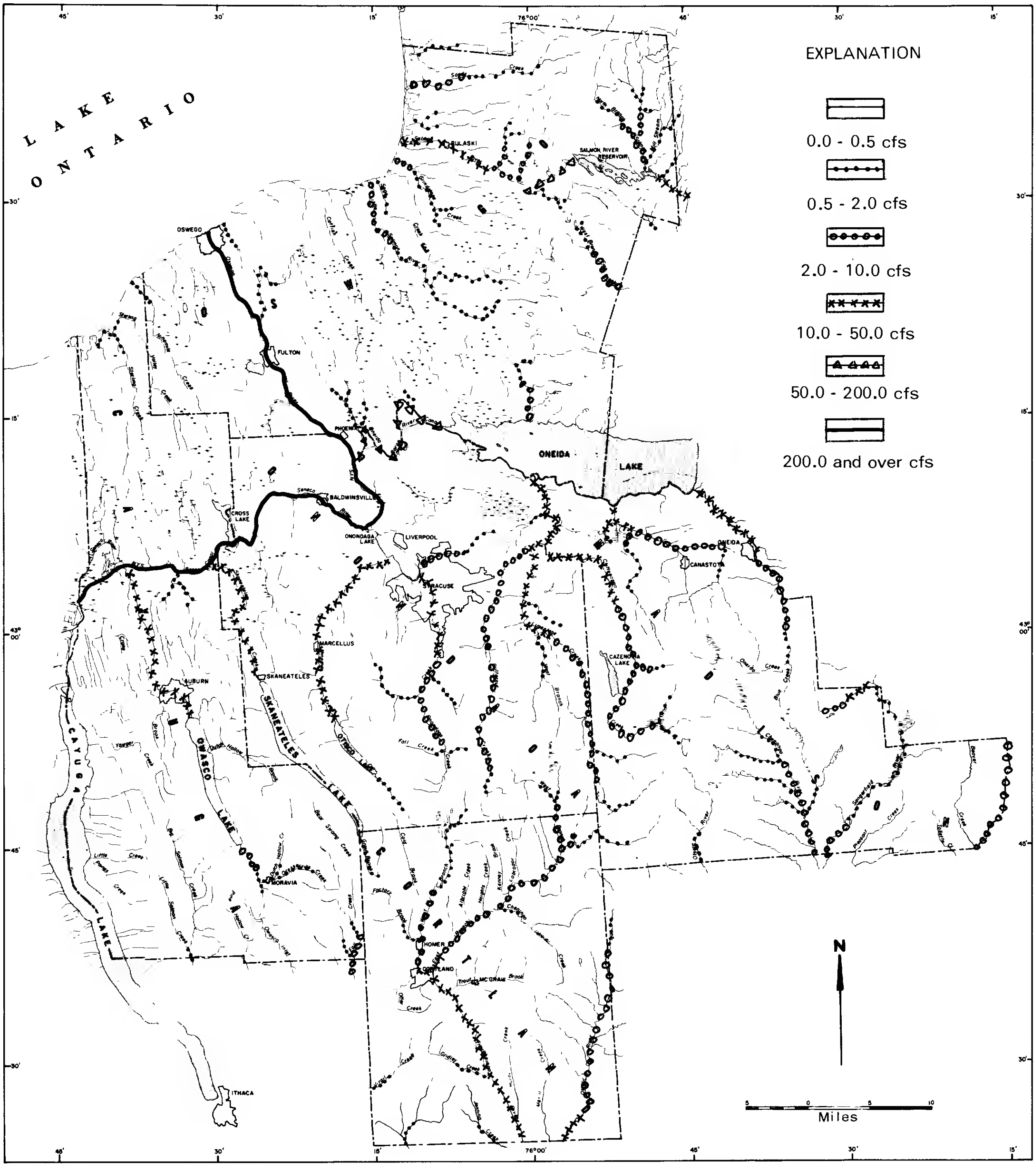

Figure 13.--Minimum average 7-consecutive day flows with a recurrence interval of 10 years.

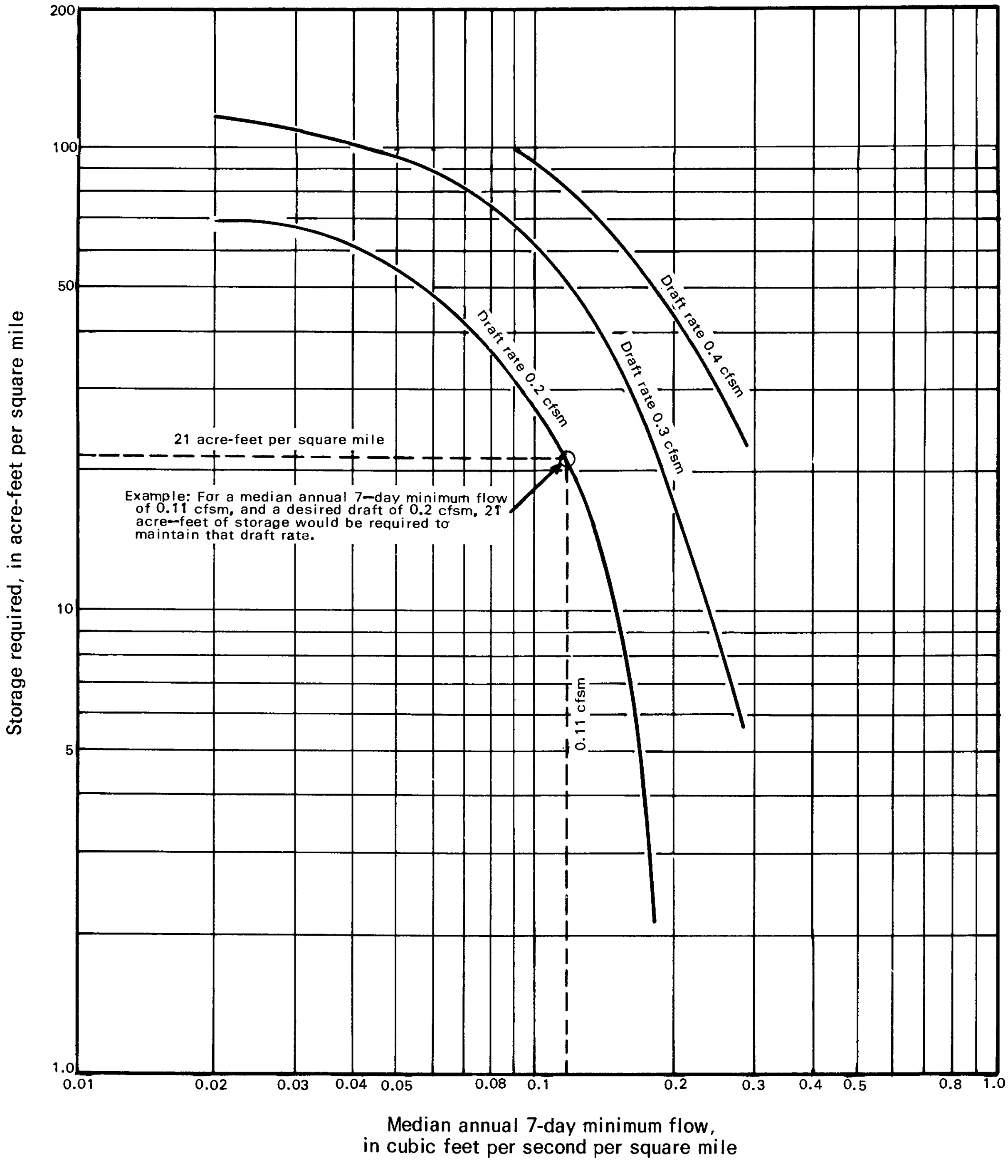

Figure 14.--Regional draft-storage curves for a 20-year recurrence interval.

By combining flood-frequency curves within homogeneous regions, three regional curves were found to be applicable within the Central New York Region, and are designated A, D, and H in figures 15 and 16. Curve A applies to a small area of northeastern Oswego County which lies in the Tug Hill Upland (fig. 15). Curve H is not truly a regional curve in that it applies only to specific reaches where the flood peaks are reduced significantly by storage or regulation. The reaches where curve H is applicable include the Erie Barge Canal, Owasco Outlet, Skaneateles Creek, Ninemile Creek, Seneca River, Oneida River, and Oswego River. Curve D applies to the remainder of the Central New York Region.

The term flood, as used in this section of the report, refers only to a relatively high discharge. In this sense, the highest discharge of the year for a given stream would be considered a flood even if the stream stayed within its banks and no damage occurred. This view is taken to facilitate statistical analysis of yearly peak discharges, the larger ones of which do cause inundation and damage.

Flood magnitudes are influenced by many factors including drainage area, land and stream slopes, air and water temperatures, channel storage, soil depth, and lakes and swamps. Of these, drainage area has by far the most significant influence. The mean of the annual floods, which has been shown to have a recurrence interval of 2.33 years, was used as the index to determine hydrologic areas. By plotting drainage area against the mean annual flood for each station with sufficient record, 10 hydrologic areas were defined in New York State and reported by Robison (1961). Of these, only areas 1 and 9 are represented in the Central New York Region. Their curves are shown in figure 17. An additional curve (labeled 12) was developed to be applied to the stream reaches where flood-frequency region curve H applies. In the Central New York Region flood-frequency regions A and D also coincide areally to hydrologic areas 1 and 9, respectively. In most other areas of the State, the boundaries do not coincide. This demonstrates the major effect of the Tug Hill Upland on the otherwise homogeneous flood characteristics of the five-county area.

Before applying the regional flood relationships to a design problem, it is necessary to select a recurrence interval. If the type of structure or its location is such that flooding would cause loss of life or great property damage, then the design will be for a flood which will probably never be exceeded. For most structures, however, the design will probably be selected on the basis of economics. It is likely that most design floods will fall within the frequency range presented in this report.

Once the recurrence interval of the design flood is chosen, an experienced hydrologist can determine its magnitude by following these steps:

1. Determine the drainage area in square miles above the selected site and the hydrologic area in which the site is located.

2. Determine the mean annual flood for the site from the appropriate curve in figure 17.

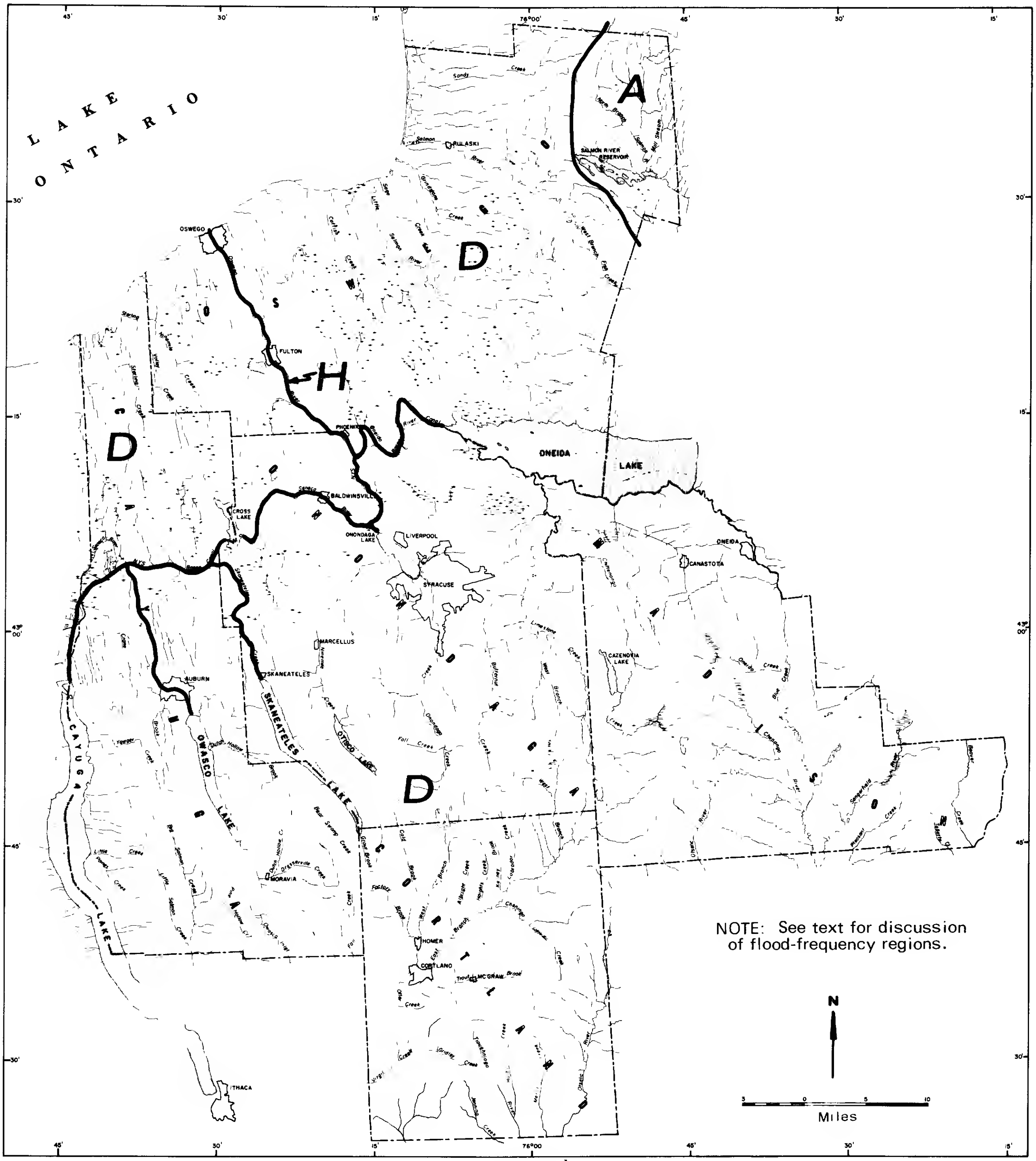

Figure 15.--Flood-frequency regions.

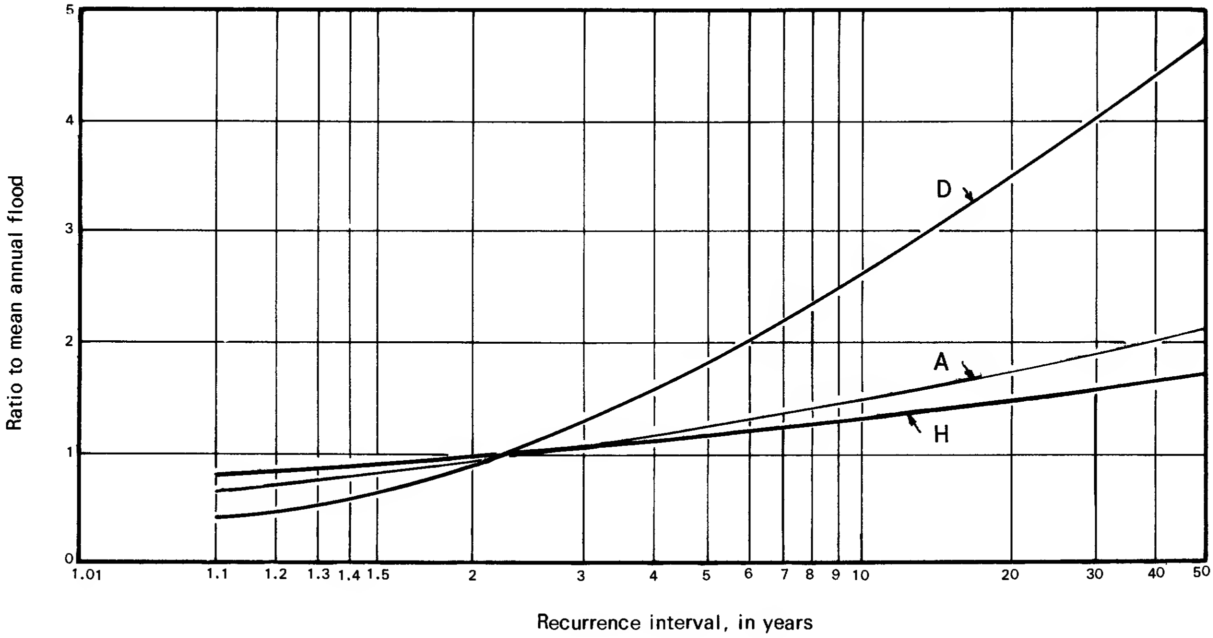

Figure 16.--Frequency of annual floods for regions A, D, and H.

3. Determine the ratio to mean annual flood for the selected recurrence interval from the appropriate curve in figure 16.

4. Multiply the ratio to mean annual flood (step 3) by the mean annual flood (step 2) to obtain the design flood magnitude.

5. A complete flood-frequency curve for a specific site in the region may be obtained if desired by repeating steps 3 and 4 for various recurrence intervals.

Generally, a frequency curve developed by this method gives a better indication of the frequency of future floods at a site than a curve from streamflow records at the site alone, provided the hydrologic areas and flood-frequency regions used to develop the regional curves are truly homogeneous. If this condition is met, then any variations experienced between flood magnitudes in adjacent streams during a given period of time may be ascribed to chance.

For example, consider two basins which are hydrologic replicas of each other. Several higher intensity storms on one basin over a period of several years may produce different flood-frequency curves for each basin. However, we would expect these chance variations to average out over a long period of time and the flood-frequency curves to approximate each other. The method described by Robison (1961) has the advantage of tending to average out these chance variations. One disadvantage is, of course, that no two basins are exactly alike and homogeneity can only be approximated.

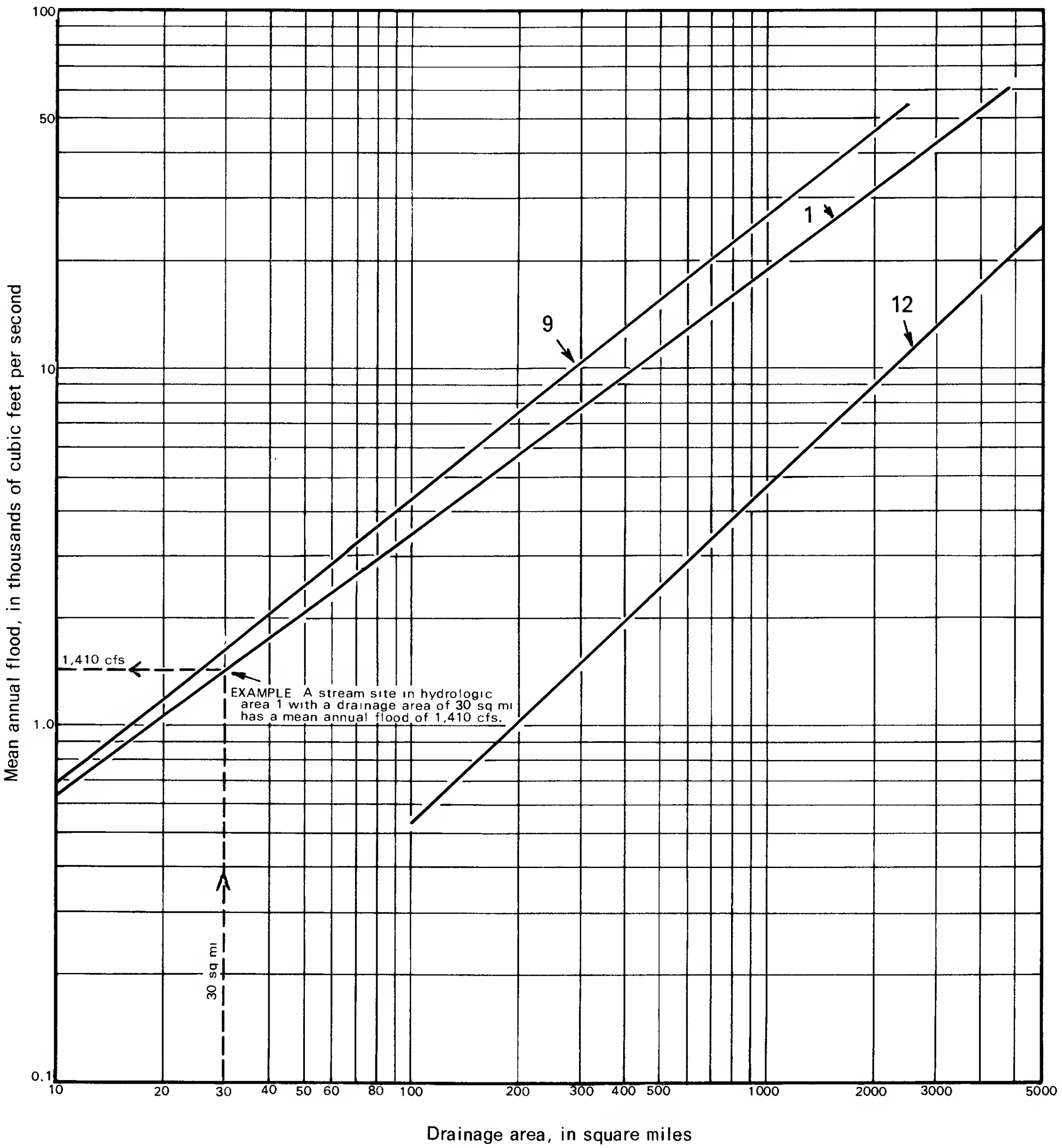

Figure 17.--Variation of mean annual flood with drainage area in hydrologic areas 1, 9, and 12.

Flood-frequency relations presented here should not be extrapolated beyond the limits shown. Only limited data are now available for streams with drainage areas less than 10 square miles and relatively short periods of streamflow record limit the prediction of recurrence intervals to 50 years.

REGIONAL FLOOD-VOLUME FREQUENCY

Although peak discharges usually control the amount of flood damage, often it is desired to prevent a flood in the first place by providing detention storage during high-flow periods. Knowledge of peak discharges alone does not provide sufficient information to design the needed storage facilities. An indication of the total volume of water associated with the high-flow period is required.

O'Donnell and Hood (written communication, 1967) developed regionalized flood-volume frequency relations for the Oswego River basin, which covers 56 percent of the five-county area. On the basis of known similarities with respect to flood characteristics, these relations may reasonably be assumed to apply also to the remaining 44 percent of the Central New York Region. When highest consecutive-day average discharges were expressed as ratios to the mean annual flood, it was found that two sets of regional curves applied to the Central New York Region. These curves are shown in figures 18 and 19 and correspond areally to the flood-frequency regions A and D discussed in the previous section. A third set of flood-volume frequency curves presumably would apply to the reaches to which curve H of figure 16 applies.

To illustrate the use of these relations, assume the following hypothetical situation. It is desired to provide detention storage for high flows by a proposed dam to control destructive floods downstream. The drainage area above the proposed damsite is 30 square miles. It is desired to provide protection for a 50-year flood, and the critical flow period associated with the 50-year flood is assumed to be 7 days. To determine the amount of water associated with this flow period, the hydrologist follows this procedure:

1. Determine the hydrologic area within which the upstream drainage area lies. (In this case, assume it lies in hydrologic area 1.)

2. Determine the mean annual flood at a site from figure 17, (for a drainage area of 30 square miles, 1,410 cfs).

3. From figure 18, determine the discharge, in ratio to mean annual flood, associated with a 50-year recurrence interval and a 7-day flow period, (0.56).

4. Multiply the discharge, in ratio to mean annual flood, by the mean annual flood, (1,410 cfs X 0.56 = 790 cfs).

This figure of 790 cfs is the average flow during the 7-day period. The volume of water associated with the period is 790 X 7 = 5,530 cfs-days, or 10,970 acre-feet. We expect that this volume of water (or more) will flow past the site during some 7-day period on an average of once in 50 years. The difference between this flood volume and the volume that the stream can "safely" carry without causing flood damage may then be used as a basis for the design of detention storage facilities for floodflows.

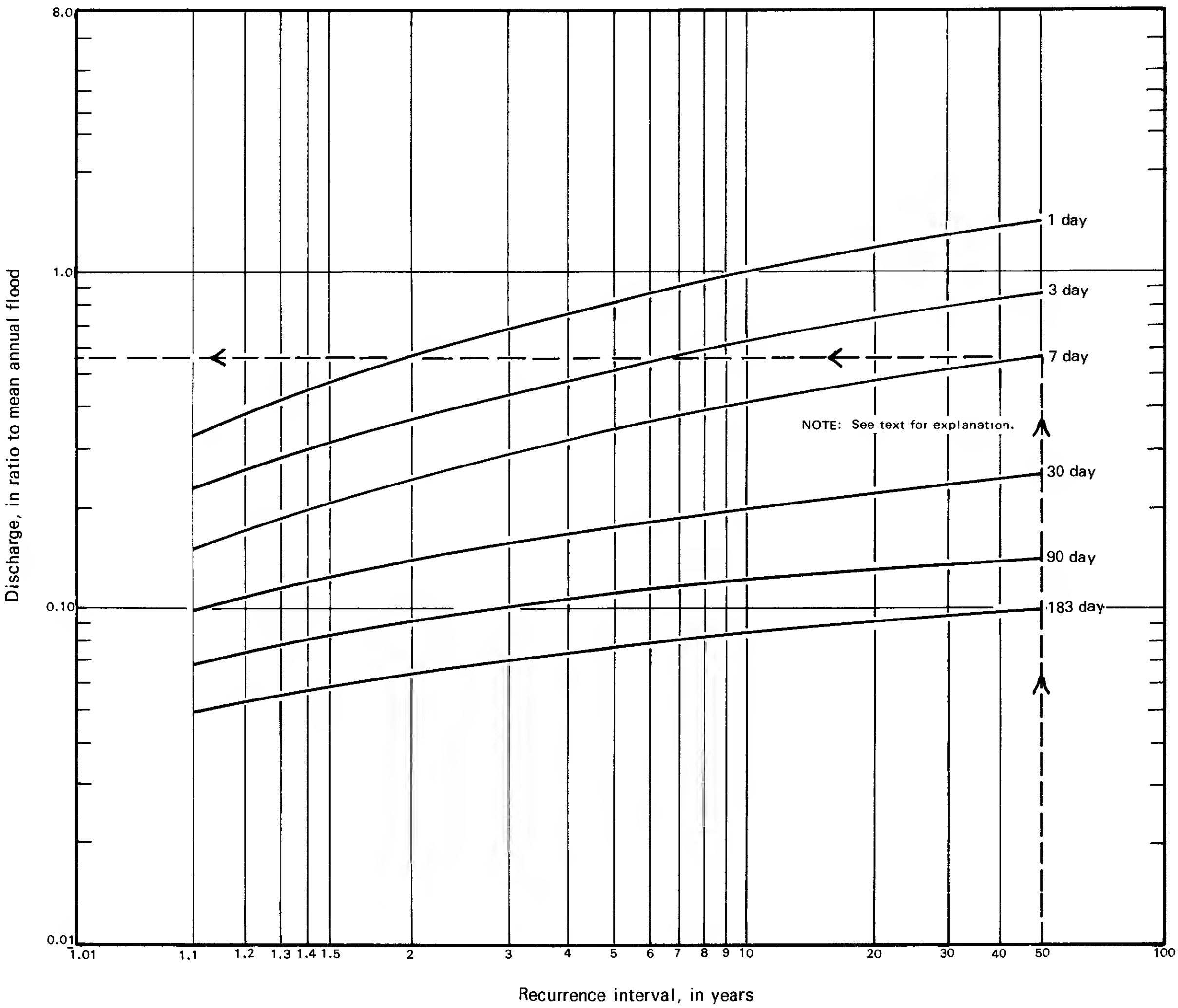

Figure 18.--Flood-volume frequency relations for region A.

Flood volumes may be estimated in a similar manner for other sites for various recurrence intervals and flow periods. In the design of flood detention facilities, the selection of a recurrence interval depends largely on the size of the drainage area. Small streams tend to rise and fall rapidly and, for many of these, the critical flow period often is as little as 1 day. Larger streams usually require selection of a longer critical flow period, but probably never more than 7 days in New York State. Regional curves for periods more than 7 days are useful in the design of reservoirs for water supply, and give an indication of the probability of the reservoir filling each spring, when most high-flow periods occur.

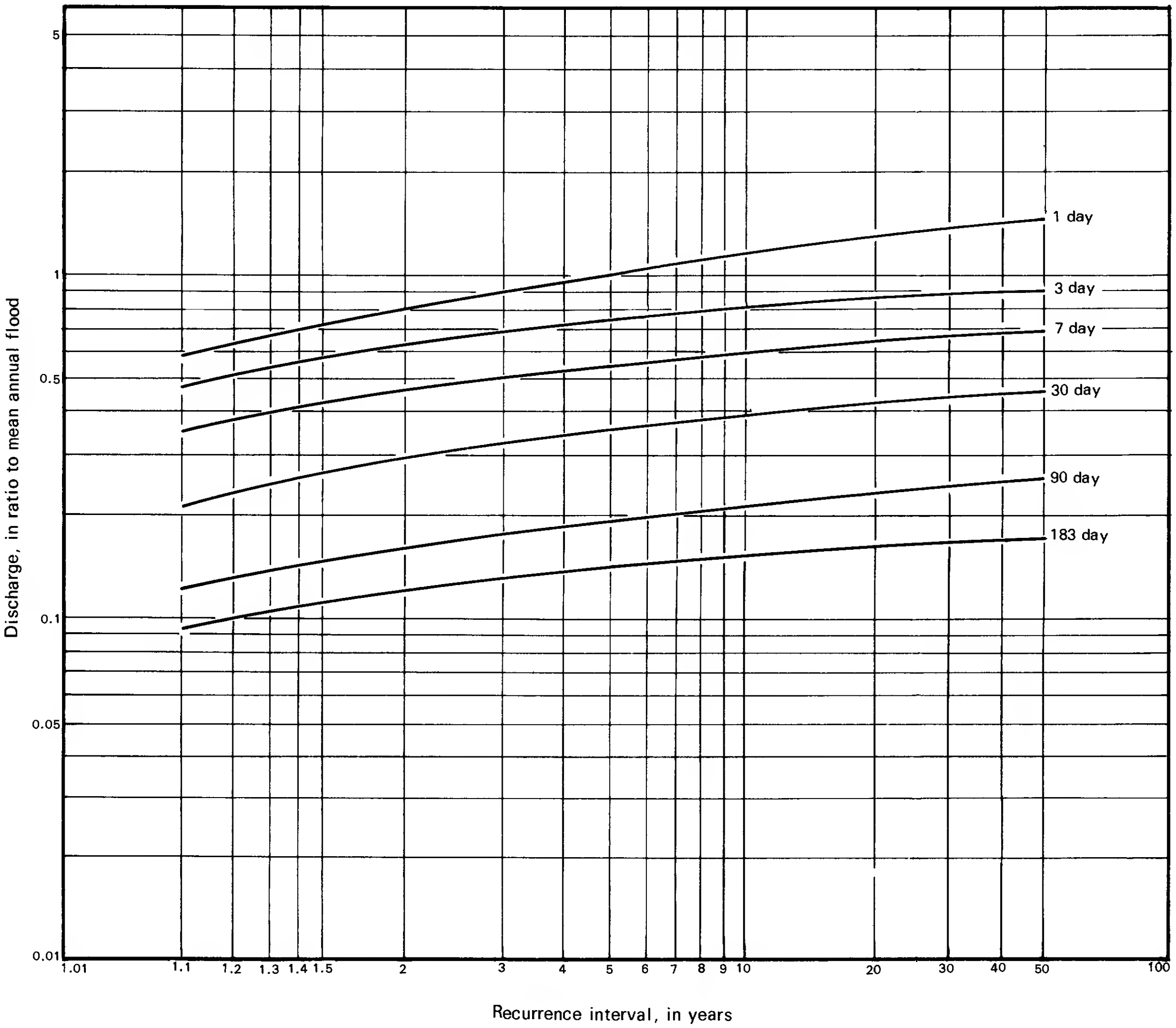

Figure 19.--Flood-volume frequency relations for region D.

QUALITY OF WATER

CHEMICAL QUALITY

The quality of the water, especially the ground water, is a very important consideration in planning the development of the Central New York Region. Because it is in contact with soluble materials for a much longer time than surface water, ground water tends to contain much more dissolved minerals.

What constitutes satisfactory quality, of course, depends on the use to which the water is to be put. In this region, most of the water is, and will be, used for various domestic and industrial purposes. Chemical quality requirements for industry are many and varied. They have been summarized by McKee and Wolf (1963, p. 92-106) and will not be discussed here. Standards for drinking water for New York are defined in Part 72 of the Administrative Rules and Regulations of the State of New York (1964). To conform with these standards, the maximum permissible concentrations of the common ions are:

Chemical constituent	Milligrams per liter
Chloride	250
Iron	.3
Manganese	.3
Nitrate	10
Sulfate	250
Total dissolved solids	500

The total dissolved solids in a water sample gives a good indication of the overall quality of the water. If the total dissolved solids is high, the water is almost certain to contain large amounts of one or more of the undesirable ions such as sulfate or chloride, or to be excessively hard. A quick check on the total dissolved solids can be obtained by measuring the specific conductance of the water. The total dissolved solids, in milligrams per liter, can be estimated as two-thirds of the specific conductance, measured as micromhos per centimeter at 25° C.

Another important consideration, especially for domestic use, is the hardness of the water. This manifests itself in increased consumption of soap and the formation of a scum. Hardness also causes the formation of scale in hot-water heaters, pipes, cooking utensils, and boilers.

The hardness of water classification of Collins, Lamar, and Lohr (1934, p. 17-18) has been generally accepted. Under this classification, water having a hardness of 60 mg/l or less is considered "soft." However, water with a hardness near 60 mg/l may have to be softened for some industrial uses. Water containing 61 to 120 mg/l of hardness is "moderately hard" and will have to be softened for many industrial uses; it may be softened for household use. Collins, Lamar, and Lohr report that it is

customary to reduce the hardness of municipal supplies to less than 120 mg/l. Water having a hardness of 121 to 180 mg/l is considered "hard" and generally is softened for most uses. Water having a hardness of more than 180 mg/l is considered "very hard."

The alkaline-earth metals, calcium and magnesium, are the principal constituents that cause hardness of water. Hardness also is caused by aluminum, iron, manganese, strontium, zinc, and free acid, but these generally are present in water only in very small amounts. It follows, therefore, that hard water will have a much higher calcium and magnesium content than soft water.

The quality of water is often poor in the broad zone shown running across the middle of the Central New York Region (fig. 1). This is due mainly to the presence of highly soluble salt and gypsum in the middle shale units. Water flowing over and through these units has dissolved much of the salt and gypsum, causing the high sulfate, chloride, and total dissolved solids content in the local water. Another cause of the high mineral content is the discharge of some industrial wastes into the water system.

Additional development of the water resources in the Central New York Region can affect the chemical quality of the water. Heavy or prolonged pumping from wells can deplete the local supply of good water and cause water of poorer quality to move into the wells. Conversely, heavy pumping of a shallow well along a stream may result in the improvement of the water quality. Because surface water generally is less highly mineralized than ground water, heavy pumping may increase the amount of surface water entering an aquifer, and the quality of the water in the aquifer will be improved. Flow in many of the streams of the study area is used to dilute sewage and industrial wastes which are discharged to the streams. Increased withdrawals from the streams could reduce the flow to the point that there would not be enough flow to sufficiently dilute the wastes.

The following discussions are based on analyses of about 100 ground-water samples and about 200 surface-water samples. Many of the analyses did not include determinations of certain constituents, so that fewer analyses are available for certain constituents. For example, only 52 analyses of ground-water samples included a determination of total dissolved solids. Hardness and chloride content are so important that they were included in all the analyses.

QUALITY OF THE GROUND WATER

The chemical quality of the ground water from the different hydrologic units is summarized in table 3. The following paragraphs discuss the quality of the water in relation to the hydrologic units.

The lower shale unit seems to have the best quality water in the area, but only three analyses are available. Total dissolved solids ranged from

Table 3.--Range in concentration of selected mineral constituents in water from the various hydrologic units

(Concentrations given in milligrams per liter)

Hydrologic unit	Number of analyses	Iron (Fe)	Manganese (Mn)	Sulfate (SO_4)	Chloride (Cl)	Total dissolved solids	Total hardness
Sand and gravel	49	0.00-2.40	0.00-0.25	13-3,360	0.2-42,500	100-2,100	52-4,420
Till	4	.02- .04	--	24-69	1.9-4.4	199	136-600
Upper shale (7)	13	.06- .12	.02- .08	3-1,310	8.6-6,690	297-13,200	10-1,280
Limestone (6)	6	.20- .90	.00- .01	44-182	3-15	372-900	319-680
Middle shale (5)	11	.00-3.50	.00- .13	439-3,510	3.6-21,200	1,560-34,000	490-5,050
Dolomite (4)	3	.19-1.30	.01- .02	24-72	2.2-59	344	118-300
Sandstone and shale (3)	2	.03- .43	.02	.2-.9	18-10,000	219-16,200	96-2,710
Sandstone (2)	9	.10- .62	.02-1.10	2.5-46	1.8-20	81-642	52-185
Lower shale (1)	3	.10- .58	.00- .18	6-94	2.1-3.3	80-89	56-64

80 to 89 mg/l, and hardness ranged from 56 to 64 mg/l. Iron, however, may be a problem. Two of the three samples contained more than 0.3 mg/l, but the highest was 0.56 mg/l.

Without doubt, the poorest water is that from the middle shale unit. This is to be expected because this unit contains considerable amounts of salt and gypsum, which are readily dissolved. Total dissolved solids ranged from 1,560 to over 34,000 mg/l, and hardness ranged from 490 to 5,050 mg/l. Chloride concentrations were as high as 21,200 mg/l, and sulfate concentrations were as high as 3,510 mg/l. Iron also tends to be a problem in some localities.

Water from the limestone unit also is of rather poor quality. Total dissolved solids ranged from 372 to about 900 mg/l, and the hardness, as would be expected, ranged from 319 to 680 mg/l. Iron may also be a problem.

Water from the other units is generally of better quality, although at least one sample from each unit had high total dissolved solids and hardness. Only 2 of 13 samples from the upper shale unit contained over 500 mg/l total dissolved solids. Water in the unconsolidated deposits tends to reflect the influence of the underlying bedrock.

Although it is not always true, it seems that throughout most of the study area water from deep gravel deposits is high in iron, water from shallow gravel deposits is very hard, and water from the bedrock is apt to be hard and high in iron. In general, water in the Susquehanna River basin is better than that in the Oswego River basin.

QUALITY OF THE SURFACE WATER

Water in streams is a mixture of overland runoff and more highly mineralized ground-water discharge, although at different times or places the entire flow may be from either source alone. Thus, during base-flow periods, when most of the water in streams is from ground water, concentrations of dissolved solids are at their highest. Conversely, during floods most of the flow is from water that has passed quickly overland with little opportunity to dissolve minerals. At these times, concentrations of dissolved solids are at their lowest.

Figures 20 and 21 show areas where more than the recommended limits of total dissolved solids and sulfate occur in the surface waters of the Central New York Region. The maps, adapted largely from W. J. Shampine (written communication, 1967) of the U.S. Geological Survey, are based on chemical analyses of water samples collected during periods of base flow. As such, the maps reflect the worst chemical-quality conditions with respect to time.

Notice, from the dissolved solids map, that water from many streams exceeds, in some reaches, the 500 mg/l maximum limit recommended by New York State. Although water from most streams contains less than this amount,

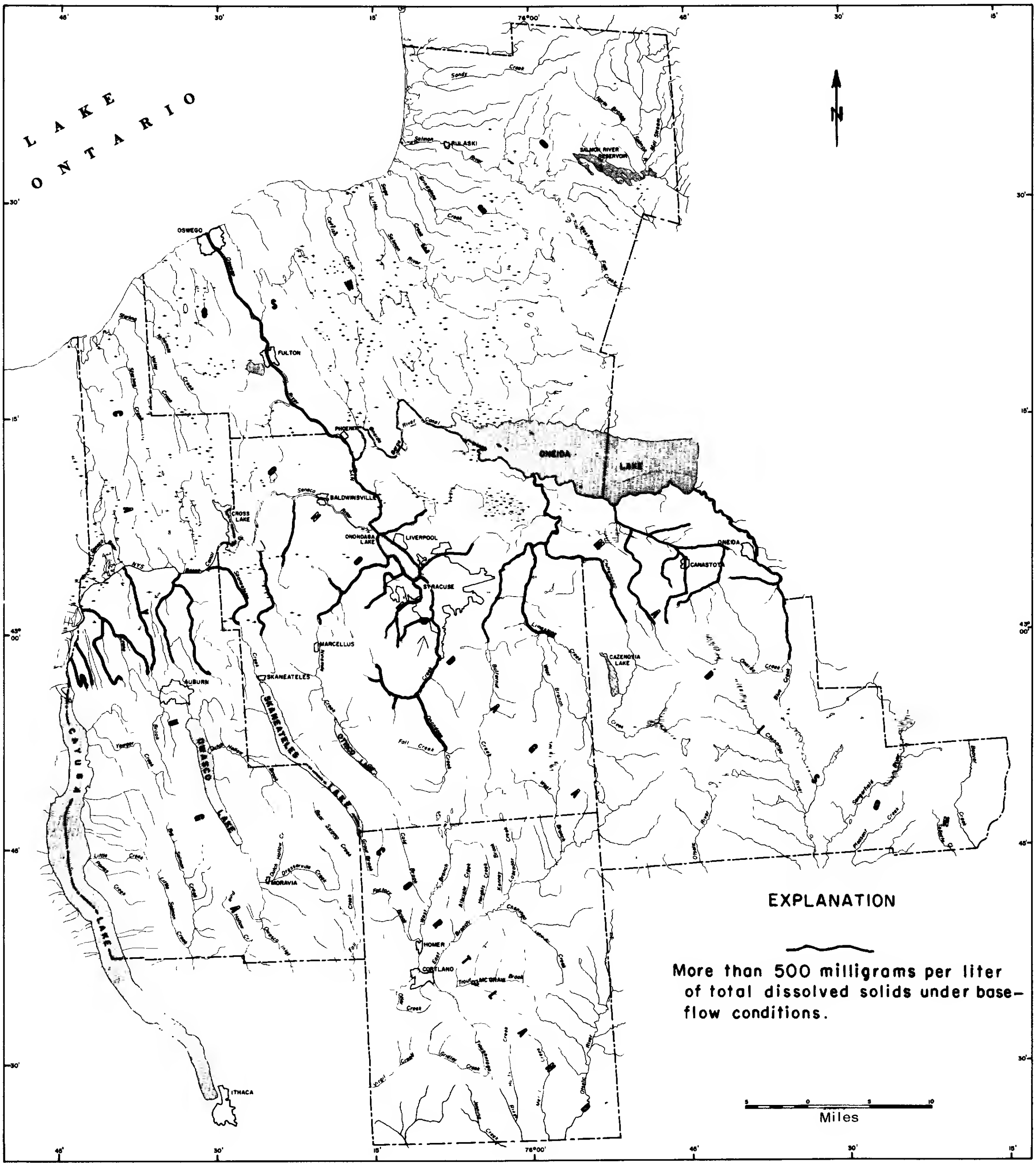

Figure 20.--Surface waters containing more than 500 milligrams per liter of total dissolved solids during base-flow conditions.

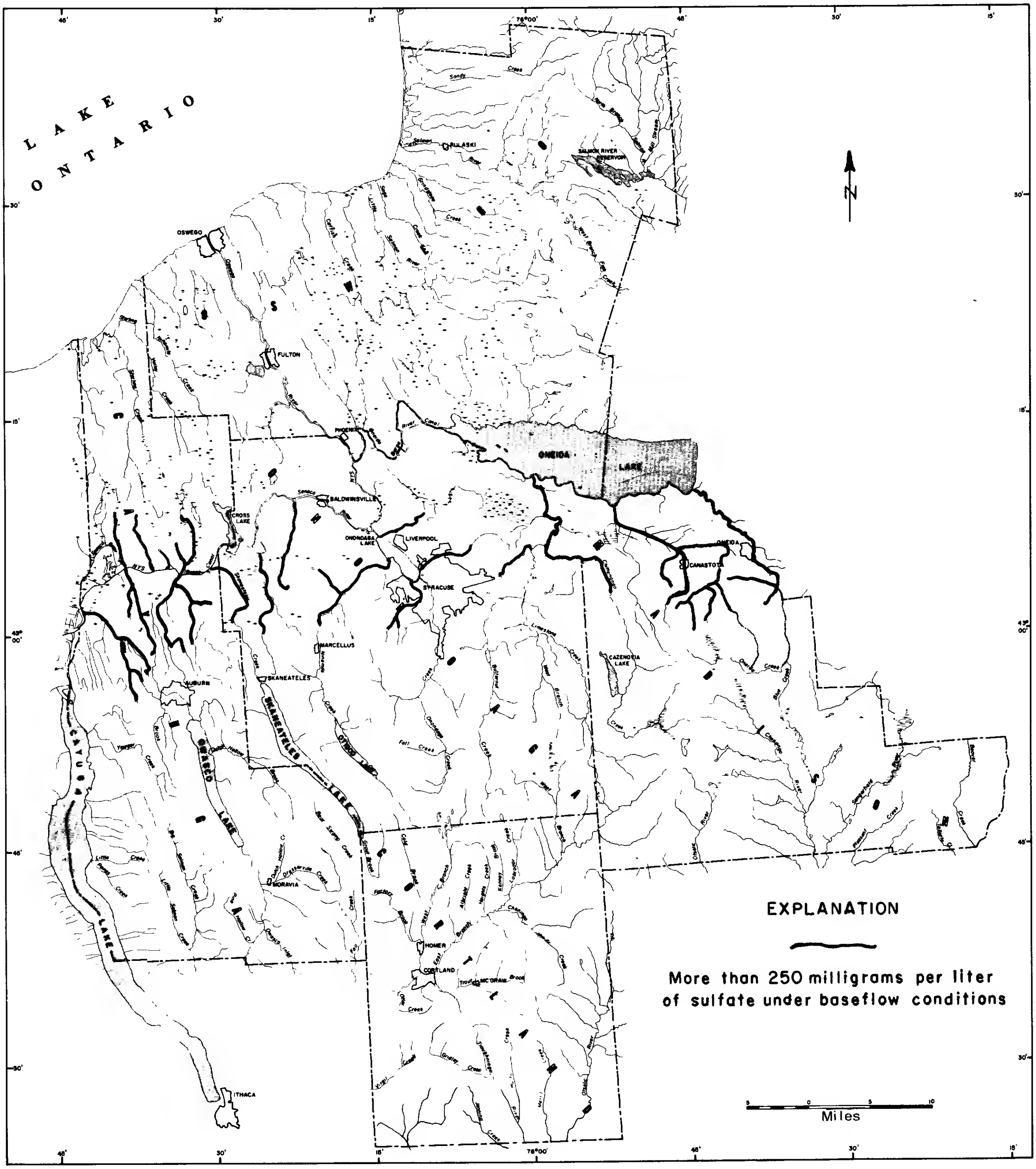

Figure 21.--Surface waters containing more than 250 milligrams per liter of sulfate during base-flow conditions.

only a few streams, notably those draining the lower shale and sandstone units in the northeastern part of the region, contain water that might be described as excellent. In these units, dissolved solids commonly amount to less than 100 mg/l and the water in most cases is soft.

Many streams flowing north from the upper shale unit in the southern part of the study area undergo a dramatic change in chemical quality as they pass through the middle shale unit (pl. 2). Jumps of 500 to 1,000 mg/l of dissolved solids are common. The "natural" surface waters of this area often exceed 1,000 mg/l of dissolved solids. Ninemile Creek at Syracuse sometimes exceeds 13,000 mg/l of total dissolved solids, though this is due in large measure to manmade pollution. It is quite conceivable that this area contains the most highly mineralized nonmarine surface waters in New York State.

The water quality of the Oswego River at its mouth is a fairly good summary of the surface-water quality of the five-county area as a whole. Dissolved solids content under base-flow conditions usually ranges between 500 and 1,000 mg/l. Hardness, as $CaCO_3$, usually exceeds 300 mg/l. Chloride usually exceeds 250 mg/l, and sulfate ranges between 50 and 100 mg/l. In other words, the base-flow chemical quality of the surface waters of the Central New York Region averages out to be poor, although most communities have managed to locate water supplies of generally good quality. Lakes, especially, make good surface-water supplies, partly because the large amount of water in storage makes for a relatively constant water quality. The city of Syracuse utilizes Skaneateles Lake for its water supply, and Otisco Lake serves many other communities in Onondaga County.

POLLUTION

Pollution is usually the result of man's activities, and comes primarily from sewage and industrial wastes. Most pollution problems are found in surface water; except for cavernous aquifers, such as the limestone and middle shale units, aquifer materials generally act as filters and remove pollution in suspension (but not in solution) before the water travels very far. Shallow wells located near cesspools, septic tanks, stock yards, and the like are the ones most likely to become polluted, especially if the well casing is not adequately sealed at the surface, and if the well is downgradient from the source of the pollutant.

Figure 1 shows the areas in the Central New York Region where the surface water is likely to be polluted. It is readily apparent that most of these areas are concentrated around and downstream from the heavily populated areas. Onondaga Lake, which is perhaps the most heavily polluted body of water in New York State, is a dramatic example of the effect of urbanization on the quality of the water.

No information is available as to polluted ground-water supplies, and any pollution that may occur in the area probably is local in nature. The ground-water supplies most susceptible to pollution are those obtained from shallow wells, especially dug wells. Septic tanks, cesspools, garbage

dumps, and barnyards are likely sources of pollution to ground water, especially if they are located near a well, or near fractures in a limestone aquifer. Sand and gravel deposits tend to act as natural filters, and ground water loses its pollution (except dissolved pollutants) after percolating for a few hundred feet. In limestone aquifers, however, there is little filtering action, and the ground water may remain polluted for long distances from the source of pollution.

Dug wells, and other wells that are not tightly sealed at the surface, are very susceptible to pollution because it is fairly easy for polluted surficial water to run down the casing to the water table and then be pumped out of the well.

A method for evaluating the potential for pollution of a waste-disposal site has been derived by LeGrand (1964). This method should be useful to local planners who can incorporate their familiarity with the area into an evaluation.

FUTURE DEVELOPMENT OF WATER RESOURCES

The Central New York Region is developing at a rate faster than other parts of the State. Between 1950 and 1960, the population increased 18.6 percent (New York State Department of Commerce, 1963, p. 2) and this high growth rate seems likely to continue in the forseeable future. Development of the water resources of the region will probably take place at an even faster rate.

A major aspect of future development will be the search for additional water supplies to furnish rapidly growing communities. Surface-water supplies, which furnish most of the large communities, generally are adequate for present needs, and the large quantities of water available allow for future expansion. Most of the smaller communities, whose water needs are more modest, will prefer to develop ground-water supplies because of the more constant temperature and the lessened danger of pollution which ground water offers. One of the major drawbacks, however, is the high degree of mineralization of the ground water in many parts of the five-county area.

Two areas where large amounts of ground water are available for future use are: (1) the sand and gravel deposits of the Homer-Cortland area, and (2) the cavernous dolomite and limestone aquifers of the central part of the study area. Wells drilled in the sand and gravel deposits of the Homer-Cortland area quite often yield more than 500 gpm of good-quality water, and in many areas recharge is available from the West Branch Tioughnioga River. The large quantities of water available from the cavernous dolomite and limestone units, however, are almost invariably excessively hard; are capable of transmitting pollution; and the percentage of wells having large yields is small. In other respects the water obtained is usually satisfactory. Additional promising areas for future development of municipal water supplies may be inferred from previous discussions of the ground-water resources.

Damaging floods have occurred on most major streams of the Central New York Region. Several courses of action are available to control future flood damages. Flood-plain zoning is becoming more and more vital as communities build more and more along the riverbanks. Channel capacities may be enlarged in critical reaches. Flood-control reservoirs have been and will be built on some streams to reduce peak flows. Also, improvements are being and will be made on many lake outlets to better control lake levels.

The irrigated acreage in the Central New York Region amounts to only about 12,000 acres at present. It is estimated that there will be almost an eightfold increase by the year 2020, to about 90,000 acres. Water presently used amounts to about 10 mgd over the 4-month growing season and about 80 mgd will be required by the year 2020 1/. It should be noted that

1/ Figures estimated from information in New York State Water Resources Commission, 1967, p. 38.

irrigation is a consumptive use of water and much of it is lost to the region through evapotranspiration. Most of this irrigation water comes from surface sources, although it is likely that the percentage of ground water used will increase somewhat in the future.

Pollution of surface water is a serious problem in the populous areas of the region, particularly in the Syracuse area. As the New York State program for pure waters takes effect, however, the natural quality of the waters will be restored to a large degree. Pollution of the ground water has not been a serious problem in the past and probably will not be in the future, providing adequate protective measures are taken if and when needed.

The rather poor chemical quality of many of the waters in the region has been a serious problem in the past and doubtless will continue to cause problems in the future. Water hardness is a widespread problem in the area; high sulfate content and high chloride content of both surface and ground waters will continue to cause occasional problems in the search for water supplies, as will high iron content from some ground water. Sulfate and chloride are difficult and expensive to remove from water, but iron may be easily and inexpensively removed by aeration.

The waters of the Central New York Region constitute a hydrologic system, and it is impossible to change one part or aspect of it without having some effects, good or bad, on other parts. Water managers in developing the water resources should consider all consequences of development and take advantage as much as possible of the favorable aspects, while minimizing unfavorable effects. A reservoir, for example, may be put to multiple uses: flood control, irrigation, low-flow augmentation, recreation, water-quality control, and water supply. Some of these uses, however, may conflict and part of the challenge of development of a reservoir or lake is to control water levels in a way which will satisfy the competing interests.

Similar problems arise in other facets of development. Large scale pumping from aquifers adjacent to streams may induce enough recharge from the stream to seriously reduce the flow of the stream. Channel enlargement to reduce flood hazards in a given stream reach may contribute to increased flood hazards downstream.

Available hydrologic information about the study area is adequate for general planning purposes, but for complex projects and more advanced planning, more intensive studies will be necessary. Information to be used for developing large ground-water supplies, for example, would include test drilling to determine the thickness and extent of the aquifers, and pumping tests as needed to determine the hydrologic properties. More streamflow information is needed to better define characteristics of low, high, and medium flow. Limnological studies, especially of the larger lakes, are more than ever desirable now because of the greatly increased recreational use of the lakes. Finally, more detailed studies are needed to better define the variations of water quality with respect to both time and location.

REFERENCES CITED

Asselstine, E. S., 1946, Progress report on ground-water conditions in the Cortland Quadrangle, New York: New York Water Power and Control Comm. Bull. GW-16, 49 p.

Broughton, J. G., Fisher, D. W., Isachsen, Y. W., and Rickard, L. V., 1966, Geology of New York, a short account: New York State Mus. and Sci. Service Educ. Leaflet 20, 45 p.

Collins, W. D., Lamar, W. L., and Lohr, E. W., 1934, The industrial utility of public water supplies in the United States, 1932: U.S. Geol. Survey Water-Supply Paper 658, 135 p.

Cross, W. P., 1963, Low-flow frequencies and storage requirements for selected Ohio streams: Ohio Dept. of Nat. Resources, Div. of Water Bull. 37, 66 p.

Dalrymple, Tate, 1960, Flood-frequency analysis: U.S. Geol. Survey Water-Supply Paper 1543-A, 80 p.

Hunt, O. P., 1967, Duration curves and low-flow frequency curves of stream-flow in the Susquehanna River basin, New York: New York Water Resources Comm. Bull. 60, 52 p.

Knox, C. E., and Nordenson, T. J., 1955, Average annual runoff and precipitation in the New England-New York area: U.S. Geol. Survey Hydrol. Inv. Atlas, HA-7.

LeGrand, H. E., 1964, System for evaluation of contamination potential of some waste disposal sites: Am. Water Works Assoc. Jour., v. 56, no. 8, p. 959-974.

McKee, J. E., and Wolf, H. W., eds., 1963, Water quality criteria: State of California Water Quality Control Board Pub. 3-A, 548 p.

New York State Department of Commerce, 1963, Business fact book, 1963, Syracuse area, pt. 2, population and housing: 28 p.

New York State Water Resources Commission, 1967, Developing and managing the water resources of New York State: Albany, N. Y., New York State Conserv. Dept., Div. of Water Resources, 52 p.

Parker, G. G., Cohen, Philip, and Foxworthy, B. L., 1967, Artificial recharge and its role in scientific water management, with emphasis on Long Island, N. Y.: Am. Water Resources Assoc. Proc., Natl. Symposium on Ground-Water Hydrology, San Francisco, California, p. 193-213.

Reed, J. E., Deutsch, Morris, and Wiitala, S. W., 1966, Induced recharge of an artesian glacial-drift aquifer at Kalamazoo, Michigan: U.S. Geol. Survey Water-Supply Paper 1594-D, 62 p.

Robison, F. L., 1961, Floods in New York, magnitude and frequency: U.S. Geol. Survey Circ. 454, 10 p.

Searcy, J. K., 1959, Flow-duration curves: U.S. Geol. Survey Water-Supply Paper 1542-A, 33 p.

Smith, H. F., 1967, Artificial recharge and its potential in Illinois in Internat. Assoc. Sci. Hydrol. Pub. no. 72, Haifa: p. 136-142.

State of New York, 1964, Administrative rules and regulations, part 72, drinking water standards: secs. 72.1 through 72.6.

Suter, Max, 1956, High-rate recharge of ground water by infiltration: Am. Water Works Assoc., v. 48, no. 4, p. 355-360.

Thornthwaite, C. W., and Mather, J. R., 1957, Instructions and tables for computing potential evapotranspiration and the water balance: Drexel Inst. of Technology, Lab. of Climatology, Pubs. in Climatology, v. X, no. 3, p. 185-311.

Todd, D. K., 1959, Annotated bibliography on artificial recharge of ground water through 1954: U.S. Geol. Survey Water-Supply Paper 1477, 115 p.

U.S. Public Health Service, 1964, 1963 inventory, municipal water facilities, Region II, Delaware, New Jersey, New York, Pennsylvania: Public Health Service Pub. no. 775 (revised), v. 2, 168 p.

Winslow, J. D., Stewart, H. G., Jr., Johnston, R. H., and Crain, L. J., 1965, Ground-water resources of eastern Schenectady County, New York, with emphasis on infiltration from the Mohawk River: New York Water Resources Comm. Bull. 57, 148 p.

GLOSSARY OF TERMS AND ABBREVIATIONS PERTAINING TO WATER RESOURCES

Term or abbreviation	Definition
Acre-foot	Enouah water to cover an acre to a depth of 1 foot = 43,560 cubic feet, or about 326,000 gallons.
Aquifer	A formation, group of formations, or part of a formation that is water bearing; a ground-water reservoir.
Base flow	Fair-weather runoff; generally composed largely of ground-water discnarge
Bedding plane	The dividing planes that separate individual layers or beds of rock.
Cavernous aquifer	An aquifer in which the water occurs in large openings, such as caves in limestone or basalt.
cfs	Cubic feet per second.
Channel storage	The volume of water in definite stream channels above a given measuring point or "outlet" at a given time during the progress of runoff.
Climatic year	Year beginning April 1 and ending March 31. The climatic year is designated by the calendar year in which it starts.
Cone of depression	The depression, roughly conical in shape, produced in a water table by pumping from a well.
Confining bed	One which, because of its position, and its impermeability or low permeability relative to that of the aquifer, prevents or retards the natural discharge of water from the aquifer into adjacent formations.
Dip	The angle between the bedding plane and the horizontal plane.
Draft storage	The amount of water storage required to supply a certain daily draft or withdrawal.
Drawdown	The vertical distance through which the water level in a well is lowered by pumping.
Evapotranspiration	The combined loss of water from direct evaporation and through the use of water by vegetation.
Flow-duration curve	A cumulative freauency curve showing the percent of time that specified discharaes were equaled or exceeded during a given period.
gpd	Gallons per day.
gpm	Gallons per minute.
Ground-water discharge	Discharqe of water from the zone of saturation, usually by seepage to streams or other surface-water bodies. but may include the discharge from wells and springs.
Ground-water recharge	Water that is added to the zone of saturation.
Ground-water runoff	That part of the runoff which has passed into the ground, has become ground water, and has been discharged into a stream channel as spring or seepage water.
Head	Amount of water pressure at a certain point; determined by the height of water over that point.
Hydraulic gradient	Pressure gradient. As applied to an aquifer it is the rate of change of pressure head per unit of distance of flow at a given point and in a given direction.
Hydrograph	A graph showing level, flow, velocity, or other property of water with respect to time.
Impermeable	Havina a texture that does not permit water to move through it perceptibly under the head differences that commonly occur in nature
Infiltration	The flow or movement of water through the land surface into the ground.
Infiltration capacity	The maximum rate at which the soil, when in a given condition, can absorb water.
Joint	Fracture planes or surfaces that divide rocks but along which there has been no visible movement.
Low-flow frequency curve	A graph showing the recurrence interval (average return period), in years, at which the lowest mean discharge for a selected number of days during a climatic year may be expected to be no greater than a specified discharge.
mgd	Million gallons per day.
mg/l	Milligrams per liter; a measure of concentration of dissolved chemical constituents in water; equivalent to one part, by weight, in 1 million.
Moisture capacity (also called field capacity)	The amount of water a soil holds after excess gravitational water has drained away.
Permeability (coefficient of)	The rate of flow of water in gallons a day (gpd) through a cross section of 1 square foot under a hydraulic gradient of 100 percent at a temperature of 60°F.
Pollution	The presence of biological and chemical contaminants in water.
Porosity (p)	The ratio of the aggregate volume of pore spaces in a rock or soil to its total volume. It is usually stated as a percentage. (Porosity is equal to the sum of the specific yield and the specific retention.)
Runoff	The part of precipitation that appears in surface streams that are not regulated.
Safe yield	The rate at which water can be withdrawn from an aquifer without depleting the supply to such an extent that continued withdrawal at this rate is harmful to the aquifer itself, or to the quality of the water, or is not economically feasible. In practice, the safe yield is equal to or less than the mean annual recharge to the aquifer.
Screen loss (of a well)	That part of the drawdown in a pumping well that may be attributed to the restriction to free flow of water through the screen and the material immediately surrounding the screen.
Soil (zone)	A layer of loose earthy material, approximately parallel to the land surface, which has been so modified and acted upon by physical, chemical, and biological agents that it will support plant growth.
Specific capacity (of a well)	The ratio of the yield of a well to the drawdown of water level in the well at a given pumping rate; generally expressed in gallons per minute per foot of drawdown.
Static level (hydrostatic level)	That level which, for a given point in an aquifer, passes through the top of a column of water that can be supported by the hydrostatic pressure of the water at that point. Corresponds to the water table or piezometric surface under static conditions.
Storage (coefficient of)	The volume of water in cubic feet released from storage in each vertical column of an aquifer having a base 1 foot square when the water table or other piezometric surface declines 1 foot. (This is approximately equal to the specific yield for nonartesian aquifers.)
Stream infiltration	The flow or movement of water through the bed of a stream into the underlying material.
Transmissibility (coefficient of)	The rate of flow of water in gallons per day through a section of aquifer 1 foot wide and having a height equal to the saturated thickness of the aquifer, under a hydraulic gradient of 100 percent, and at a temperature of 60°F. The coefficient of transmissibility is equal to the coefficient of permeability times the saturated thickness of the aquifer.
Water table	The upper surface of a zone of saturation having an air-water interface.
Water year	Year beginning October 1 and ending September 30. The water year is designated by the calendar year in which it ends.
Zone of aeration	The zone between the water table and the land surface in which the pore spaces of the rocks are not all filled (except temporarily) with water.
Zone of saturation	The zone in which the pore spaces of rocks are saturated with water under hydrostatic pressure.

BULLETINS PUBLISHED BY THE NEW YORK WATER RESOURCES COMMISSION AND PREPARED IN COOPERATION WITH THE U.S. GEOLOGICAL SURVEY

An asterisk (*) indicates that the report is out of print, but such reports are available for consultation in certain libraries.

BULLETINS:

*GW- 1 WITHDRAWAL OF GROUND WATER ON LONG ISLAND, N. Y.
D. G. Thompson and R. M. Leggette (1936)

*GW- 2 ENGINEERING REPORT ON THE WATER SUPPLIES OF LONG ISLAND.
Russell Suter (1937)

*GW- 3 RECORD OF WELLS IN KINGS COUNTY, N. Y.
R. M. Leggette and others (1937)

*GW- 4 RECORD OF WELLS IN SUFFOLK COUNTY, N. Y.
R. M. Leggette and others (1938)

*GW- 5 RECORD OF WELLS IN NASSAU COUNTY, N. Y.
R. M. Leggette and others (1938)

*GW- 6 RECORD OF WELLS IN QUEENS COUNTY, N. Y.
R. M. Leggette and others (1938)

*GW- 7 REPORT ON THE GEOLOGY AND HYDROLOGY OF KINGS AND QUEENS COUNTIES, LONG ISLAND.
Homer Sanford (1938)

GW- 8 RECORD OF WELLS IN KINGS COUNTY, N. Y., SUPPLEMENT 1.
R. M. Leggette and M. L. Brashears, Jr. (1944)

GW- 9 RECORD OF WELLS IN SUFFOLK COUNTY, N. Y., SUPPLEMENT 1.
C. M. Roberts and M. L. Brashears, Jr. (1945)

GW-10 RECORD OF WELLS IN NASSAU COUNTY, N. Y., SUPPLEMENT 1.
C. M. Roberts and M. L. Brashears, Jr. (1946)

*GW-11 RECORD OF WELLS IN QUEENS COUNTY, N. Y., SUPPLEMENT 1.
C. M. Roberts and M. C. Jaster (1947)

*GW-12 THE WATER TABLE IN THE WESTERN AND CENTRAL PARTS OF LONG ISLAND, N. Y.
C. E. Jacob (1945)

*GW-13 THE CONFIGURATION OF THE ROCK FLOOR IN WESTERN LONG ISLAND, N. Y.
Wallace de Laguna and M. L. Brashears, Jr. (1948)

GW-14 CORRELATION OF GROUND-WATER LEVELS AND PRECIPITATION ON LONG ISLAND, N. Y
C. E. Jacob (1945)

*GW-15 PROGRESS REPORT ON GROUND-WATER RESOURCES OF THE SOUTHWESTERN PART OF BROOME COUNTY, N. Y.
R. H. Brown and J. G. Ferris (1946)

*GW-16 PROGRESS REPORT ON GROUND-WATER CONDITIONS IN THE CORTLAND QUADRANGLE, N.Y.
E. S. Asselstine (1946)

*GW-17 GEOLOGIC CORRELATION OF LOGS OF WELLS IN KINGS COUNTY, N. Y.
Wallace de Laguna (1948)

GW-18 MAPPING OF GEOLOGIC FORMATIONS AND AQUIFERS OF LONG ISLAND, N. Y.
Russell Suter, Wallace de Laguna, and N. M. Perlmutter (1949)

*GW-19 GEOLOGIC ATLAS OF LONG ISLAND. (Consists of large-scale reproductions of maps in GW-18.) (1950)

*GW-20 THE GROUND-WATER RESOURCES OF ALBANY COUNTY, N. Y.
Theodore Arnow (1949)

GW-20A BURIED PREGLACIAL GROUND-WATER CHANNELS IN THE ALBANY-SCHENECTADY AREA IN NEW YORK.
E. S. Simpson (1949)

BULLETINS PUBLISHED BY THE NEW YORK WATER RESOURCES COMMISSION AND PREPARED IN COOPERATION WITH THE U.S. GEOLOGICAL SURVEY (Continued)

BULLETINS:

GW-21 THE GROUND-WATER RESOURCES OF RENSSELAER COUNTY, N. Y.
R. V. Cushman (1950)

GW-22 THE GROUND-WATER RESOURCES OF SCHOHARIE COUNTY, N. Y.
J. M. Berdan (1950)

GW-23 THE GROUND-WATER RESOURCES OF MONTGOMERY COUNTY, N. Y.
R. M. Jeffords (1950)

GW-24 THE GROUND-WATER RESOURCES OF FULTON COUNTY, N. Y.
Theodore Arnow (1951)

GW-25 THE GROUND-WATER RESOURCES OF COLUMBIA COUNTY, N. Y.
Theodore Arnow (1951)

GW-26 THE GROUND-WATER RESOURCES OF SENECA COUNTY, N. Y.
A. J. Mozola (1951)

*GW-27 THE WATER TABLE IN LONG ISLAND, N. Y., IN JANUARY 1951.
N. J. Lusczynski and A. H. Johnson (1951)

*GW-28 WITHDRAWAL OF GROUND WATER ON LONG ISLAND, N. Y., SUPPLEMENT 1.
A. H. Johnson and others (1952)

GW-29 THE GROUND-WATER RESOURCES OF WAYNE COUNTY, N. Y.
R. E. Griswold (1951)

GW-30 THE GROUND-WATER RESOURCES OF SCHENECTADY COUNTY, N. Y.
E. S. Simpson (1952)

GW-31 RECORDS OF WELLS IN SUFFOLK COUNTY, N. Y., SUPPLEMENT 2.
Staff, Long Island office, Water Power and Control Commission (1952)

GW-32 GROUND WATER IN BRONX, NEW YORK, AND RICHMOND COUNTIES WITH SUMMARY DATA ON KINGS AND QUEENS COUNTIES, NEW YORK CITY, N. Y.
N. M. Perlmutter and Theodore Arnow (1953)

GW-33 THE GROUND-WATER RESOURCES OF WASHINGTON COUNTY, N. Y.
R. V. Cushman (1953)

GW-34 THE GROUND-WATER RESOURCES OF GREENE COUNTY, N. Y.
J. M. Berdan (1954)

GW-35 THE GROUND-WATER RESOURCES OF WESTCHESTER COUNTY, N. Y., PART 1, RECORDS OF WELLS AND TEST HOLES.
E. S. Asselstine and I. G. Grossman (1955)

GW-36 SALINE WATERS IN NEW YORK STATE.
N. J. Lusczynski, J. J. Geraghty, E. S. Asselstine, and I. G. Grossman (1956)

GW-37 THE GROUND-WATER RESOURCES OF PUTNAM COUNTY, N. Y.
I. G. Grossman (1957)

GW-38 CHLORIDE CONCENTRATION AND TEMPERATURE OF WATER FROM WELLS IN SUFFOLK COUNTY, LONG ISLAND, N. Y., 1928-53.
J. F. Hoffman and S. J. Spiegel (1958)

*GW-39 RECORD OF WELLS IN NASSAU COUNTY, N. Y., SUPPLEMENT 2.
Staff, Long Island office, Water Power and Control Commission (1958)

GW-40 THE GROUND-WATER RESOURCES OF CHEMUNG COUNTY, N. Y.
W. S. Wetterhall (1959)

GW-41 GROUND-WATER LEVELS AND RELATED HYDROLOGIC DATA FROM SELECTED OBSERVATION WELLS IN NASSAU COUNTY, LONG ISLAND, N. Y.
John Isbister (1959)

GW-42 GEOLOGY AND GROUND-WATER RESOURCES OF ROCKLAND COUNTY, N. Y.
N. M. Perlmutter (1959)

BULLETINS PUBLISHED BY THE NEW YORK WATER RESOURCES COMMISSION AND PREPARED IN COOPERATION WITH THE U.S. GEOLOGICAL SURVEY (Continued)

BULLETINS:

GW-43 GROUND-WATER RESOURCES OF DUTCHESS COUNTY, N. Y.
E. T. Simmons, I. G. Grossman, and R. C. Heath (1961)

GW-44 GROUND-WATER LEVELS AND THEIR RELATIONSHIP TO GROUND-WATER PROBLEMS IN SUFFOLK COUNTY, LONG ISLAND, N. Y.
J. F. Hoffman and E. R. Lubke (1961)

GW-45 HYDROLOGY OF THE SHALLOW GROUND-WATER RESERVOIR OF THE TOWN OF SOUTHOLD, SUFFOLK COUNTY, N. Y.
J. F. Hoffman (1961)

*GW-46 THE GROUND-WATER RESOURCES OF SULLIVAN COUNTY, N. Y.
Julian Soren (1961)

GW-47 GROUND-WATER RESOURCES OF THE MASSENA-WADDINGTON AREA, ST. LAWRENCE COUNTY, N. Y.
F. W. Trainer and E. H. Salvas (1962)

GW-48 THE GROUND-WATER RESOURCES OF ONTARIO COUNTY, N. Y.
F. K. Mack and R. E. Digman (1962)

GW-49 GROUND-WATER STUDIES IN SARATOGA COUNTY, N. Y.
R. C. Heath, F. K. Mack, and J. A. Tannenbaum (1963)

GW-50 THE GROUND-WATER RESOURCES OF DELAWARE COUNTY, N. Y.
Julian Soren (1963)

GW-51 GROUND WATER IN NEW YORK.
R. C. Heath (1964)

GW-52 WATER RESOURCES OF THE LAKE ERIE-NIAGARA AREA, N. Y.-A PRELIMINARY APPRAISAL.
A. M. La Sala, Jr., W. E. Harding, and R. J. Archer (1964)

GW-53 GROUND WATER IN THE NIAGARA FALLS AREA, N. Y.
R. H. Johnston (1964)

*54 MAXIMUM KNOWN DISCHARGES OF NEW YORK STREAMS.
F. L. Robison (1965)

55 CHLORIDE CONCENTRATION AND TEMPERATURE OF THE WATERS OF NASSAU COUNTY, LONG ISLAND, N. Y.
F. A. DeLuca, J. F. Hoffman, and E. R. Lubke (1965)

56 SUMMARY OF WATER-RESOURCES RECORDS AT PRINCIPAL MEASUREMENT SITES IN THE GENESEE RIVER BASIN, THROUGH 1963.
B. K. Gilbert and J. C. Kammerer (1965)

57 GROUND-WATER RESOURCES OF EASTERN SCHENECTADY COUNTY, N. Y.
J. D. Winslow, H. G. Stewart, Jr., R. H. Johnston, and L. J. Crain (1965)

58 GROUND-WATER RESOURCES OF THE JAMESTOWN AREA, N. Y.
L. J. Crain (1966)

59 SURFACE-WATER REGIMEN OF THE UPPER FLINT CREEK BASIN, N. Y.
D. E. Vaupel (1967)

60 DURATION CURVES AND LOW-FLOW FREQUENCY CURVES OF STREAMFLOW IN THE SUSQUEHANNA RIVER BASIN, N. Y.
O. P. Hunt (1967)

61 THE HUDSON RIVER ESTUARY-A PRELIMINARY INVESTIGATION OF FLOW AND WATER-QUALITY CHARACTERISTICS.
G. L. Giese and J. W. Barr (1967)

BULLETINS PUBLISHED BY THE NEW YORK WATER RESOURCES COMMISSION AND PREPARED IN COOPERATION WITH THE U.S. GEOLOGICAL SURVEY (Continued)

BULLETINS:

62 AN ATLAS OF LONG ISLAND'S WATER RESOURCES
Philip Cohen, O. L. Franke, and B. L. Foxworthy (1968)

63 STREAMS IN DUTCHESS COUNTY, N. Y.
G. R. Ayer and F. H. Pauszek (1968)

64 WATER RESOURCES OF THE CENTRAL NEW YORK REGION
W. G. Weist, Jr. and G. L. Giese (1969)